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**FINAL
BENCH-SCALE TREATABILITY STUDY
REPORT FOR THERMAL TREATMENT**

REMEDIAL INVESTIGATION

**RAYMARK INDUSTRIES, INC. SITE
STRATFORD, CONNECTICUT**

**For
U.S. Environmental Protection Agency**

**By
Halliburton NUS Corporation**

**EPA Work Assignment No. 42-1LH3
EPA Contract No. 68-W8-0117
HNUS Project No. 0890**

October 1994



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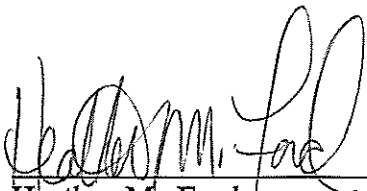
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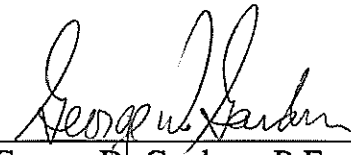

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THERMAL TREATMENT
RAYMARK INDUSTRIES SITE
STRATFORD, CONNECTICUT

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1.0 PROJECT DESCRIPTION

Halliburton NUS Corporation (HNUS) is performing a Remedial Investigation (RI) on behalf of the U.S. Environmental Protection Agency (EPA) for the Raymark Industries, Inc. Site. As part of this RI, a bench-scale treatability study was performed to evaluate the effectiveness of thermal treatment in reducing PCB concentrations of the contaminated soil-waste materials to less than 2.0 mg/kg.

1.1 Project Background

The Raymark Industries, Inc. Site located in Stratford, Connecticut, was a manufacturer of friction materials containing asbestos and non-asbestos materials, inorganics, phenol-formaldehyde resins, and various adhesives. Primary products were gasket material, sheet packing and friction materials including clutch facings, transmission plates, and brake linings. As a result of these activities, soils at the Site have been primarily contaminated with asbestos, lead, and PCBs.

For the purpose of this specification, the term soil-waste material means soils mixed with various manufacturing wastes including asbestos and other contaminated materials. Currently, at least fifteen satellite areas throughout the Town of Stratford that have been identified, each consisting of a large number of properties where Raymark waste is known to have been received and used as fill. These areas consist of commercial, residential, and municipal properties. A number of properties within the satellite areas have been designated a health hazard and are the focus of time-critical removal actions. The excavated waste from these properties is currently being stored, on a temporary basis, at the Raymark facility until a final cleanup option is selected. Based on the sampling results for soil-waste materials obtained from the Raymark Industries facility, maximum concentrations of contaminants detected are presented in Table 1-1.

1.2 Treatability Study

The primary objective of this treatability study was to determine the feasibility of using thermal treatment to reduce the PCB concentrations of the contaminated soil-waste materials to less than 2.0 mg/kg.

The secondary objective of this treatability study was to determine the effect of the thermal treatment process on the other organic compounds, asbestos, and metals content of the contaminated soil-waste materials.

As part of the treatability study, HNUS prepared a Request For Proposal (RFP) and sent it to seven qualified potential subcontractors including CleanSoils, Inc.; Halliburton Services; Kiber Environmental Services; Rust Remedial Services; Testco Tank & Pump, Inc.; VFL Technology; and Weston Services, Inc. In response to this RFP, proposals were received from two of the seven potential subcontractors, Kiber Environmental Services and Rust Remedial Services.

TABLE 1-1
MAXIMUM CONCENTRATIONS DETECTED IN SOIL-WASTE MATERIALS
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT

CONSTITUENT	MAXIMUM CONCENTRATION	DETECTION LIMIT	DEPTH (feet)
VOCs (µg/kg) SW846-3550/8240			
● Acetone	3,893	100	8 to 10
● Benzene	80.4	5	8 to 10
● 2-Butanone	28,046	100	8 to 9
● Carbon Disulfide	209	100	7 to 8
● Chlorobenzene	141,379	5	8 to 9
● 1,2 -Dichlorobenzene	195	5	8 to 9
● 1,4-Dichlorobenzene	138.0	5	8 to 9
● 1,1-Dichloroethane	2,287	5	8 to 9
● 1,2-Dichloroethane	35	5	8 to 9
● 1,1-Dichloroethene	148.6	5	15 to 17
● trans-1,2-Dichloroethene	202	5	8 to 10
● Ethylbenzene	22,644	5	8 to 9
● 2-Hexanone	109.6	50	8 to 10
● 4-Methyl-2-Pentanone	1,399	50	4 to 6
● Styrene	367	5	0 to 2
● Tetrachloroethene	20.2	5	45 to 47
● Toluene	2,569,620	5	4 to 6
● 1,1,1-Trichloroethane	116.7	5	20 to 22
● 1,1,2-Trichloroethane	544	5	48 to 50
● Trichloroethene	2,196	5	41 to 43
● Vinyl Chloride	514	10	8 to 10
● Xylenes	113,908	5	8 to 9
SVOCs/BNA (µg/kg) SW846-3550/8270			
● Acenaphtene	12.6	4.4	0 to 8
● Acenaphtelene	10.4	4.4	0 to 8
● Anthracene	36.5	4.4	0 to 8
● Benzo(a)anthracene	61.7	4.4	0 to 8
● Benzo(b)fluoranthene	35.1	4.4	0 to 8
● Benzo(k)fluoranthene	47.6	4.4	0 to 8
● Benzo(g,h,i)perylene	10.8	4.4	0 to 8
● Benzo(a)pyrene	26.1	4.4	0 to 8
● Bis(2-ethylhexyl)phtalate	27.4	3.6	0 to 10
● Butyl benzyl phtalate	16.9	3.6	0 to 10
● Chrysene	54.0	4.4	0 to 8
● Dibenzofuran	11.1	4.4	0 to 8
● Di-n-butylphtalate	36.6	5.4	6 to 11
● 2,4-Dimethylphenol	19.3	1.2	2 to 12
● Fluoranthene	170.4	4.4	0 to 8
● Fluorene	32.4	4.4	0 to 8
● Indeno(1,2,3-cd)pyrene	9.4	4.4	0 to 8
● Isophorone	33.6	3.8	92 to 102
● 2-Metylnaphtalene	6.2	4.4	0 to 8
● 2-Methylphenol (o-cresol)	3.2	1.2	2 to 12
● 3-Methylphenol (m-cresol)	55.9	1.2	2 to 12
● 4-Nitrophenol	0.5	0.4	34 to 38
● Naphtalene	5.3	4.4	0 to 8
● Phenantrene	154.3	4.4	0 to 8
● Pyrene	139.6	4.4	0 to 8

TABLE 1-1
MAXIMUM CONCENTRATIONS DETECTED IN SOIL-WASTE MATERIALS
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT
PAGE TWO OF THREE

CONSTITUENT	MAXIMUM CONCENTRATION	DETECTION LIMIT	DEPTH (feet)
Chlorinated Herbicides (µg/kg) SW846-3550/8150 <ul style="list-style-type: none"> • 2,4-Dichlorophenylacetic Acid • 2,4-D • Dinoseb • 2,4,5-T • 2,4,5-TP (Silvex) 	398 670 100 1,020 1,700	NR NR NR NR NR	2 to 12 6 to 11 2 to 12 8 to 11 38 to 48
Pesticides (µg/kg) SW846-3550/8140 <ul style="list-style-type: none"> • Triphenylphosphate • Diallate • Dimethoate • Disulfoton • Famphur • Methyl Parathion • Parathion • Phorate • Pronamide • Sulfotep • Thiazin 	203 540 125 1,000 180 680 125 340 780 125 118	NR NR NR NR NR NR NR NR NR NR NR	0 to 8 0 to 8 38 to 44 0 to 8 0 to 8 0 to 10 38 to 44 2 to 12 7 to 15 38 to 44 52 to 62
Sulfides (mg/kg) SW846-3550/9030	250	37	12 to 22
Cyanides (mg/kg) SW846-3550/9012	8.3	NR	0 to 8
PCBs (mg/kg) SW846-3550/8080 Aroclor 1268	190	0.1	0 to 10
Dioxins (µg/kg) SW846-3550/8280 TE (Toxicity Equivalent)	7.2162	N/A	0 to 10
Asbestos (% by weight) EPA Analytical Method NR <ul style="list-style-type: none"> Chrysotile Cellulose Matrix Synthetic 	40-45 30-35 99-100 1-2	N/A N/A N/A N/A	0 to 10 15 to 18.5 10 to 15 12 to 22

TABLE 1-1
MAXIMUM CONCENTRATIONS DETECTED IN SOIL-WASTE MATERIALS
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT
PAGE THREE OF THREE

CONSTITUENT	MAXIMUM CONCENTRATION	DETECTION LIMIT	DEPTH (feet)
Metals (µg/kg)			
SW846-6010/7471			
• Antimony	30,182	1,000	6 to 11
• Arsenic	130,208	200	0 to 8
• Barium	2,314,400	400	7 to 15
• Beryllium	8,400	500	0 to 4
• Cadmium	10,364	500	6 to 11
• Chromium	316,949	1,000	0 to 10
• Cobalt	87,100	5,000	0 to
• Copper	67,966,101	NR	
• Lead	57,230,769	NR	
• Mercury	1,017	100	
• Nickel	774,576	4,000	
• Selenium	6,780	NR	
• Silver	67,470	1,000	
• Thallium	781	500	
• Tin	229,730	4,000	
• Vanadium	103,000	NR	
• Zinc	13,175,675	NR	

The proposals received were evaluated independently by three senior HNUS engineers and graded against the criteria presented in the RFP, including bidder's qualifications, technical merit and adequacy of the proposed testing technology, and treatability study design. As a result of this evaluation, Rust Remedial Services was initially selected as the more technically qualified firm to perform the thermal treatment treatability study. However, Rust Remedial Services' price proposal proved to be unacceptable, even after protracted negotiations. The subcontract was then awarded to the next best qualified bidder, Kiber Environmental Services, Inc (Kiber).

One of the primary differences between the Rust and Kiber proposals (besides price) was the proposed use of a static tray system by Kiber, while Rust proposed a system that agitated the samples. HNUS decided that use of the static system would be an acceptable and conservative approach, as all contaminants would be desorbed.

Static tray tests where, soil agitation soil does not occur, are one of many methods used to simulate full-scale thermal treatment systems. The temperature at the center of the soil layer can be used as a conservative predictor of organic removal efficiencies for the processed soil. The soil temperature, rather than the oven temperature, is the parameter of interest. Use of a processed soil temperature of 900 degrees F and the benefit of better agitation produced by a full-scale thermal treatment unit allows for a margin of error in evaluating pilot-scale vs. full-scale treatment.

The initial approach for conducting the treatability study was to evaluate the effectiveness of low temperature thermal desorption (LTTD) in removing PCBs from the soil-waste materials. However, as the tests progressed, it became apparent that thermal treatment at higher temperatures (900 degrees F+), rather than at low temperatures, was necessary to achieve this goal. Documents prepared by the subcontractor and earlier HNUS work plans referred to the treatability study as LTTD; however, all efforts were devoted to thermal treatment.

HNUS prepared a Treatability Study Work Plan (Work Plan) by revising the technical specifications included in the RFP to incorporate pertinent information provided by Kiber in their technical proposal. The Work Plan is included as Appendix A.

HNUS also collected four soil-waste material samples representative of the conditions at the Raymark Industries Site and shipped them to Kiber. All four soil-waste materials samples were collected from on-site soil borings. Table 1-2 provides the key to sample identification.

Figure 1-1 shows the location of the soil borings from which the soil-waste material samples were collected. Samples were collected and shipped in accordance with an addendum to the Health and Safety Plan prepared by HNUS for the Stratford, Connecticut, Technical Assistance work assignment.

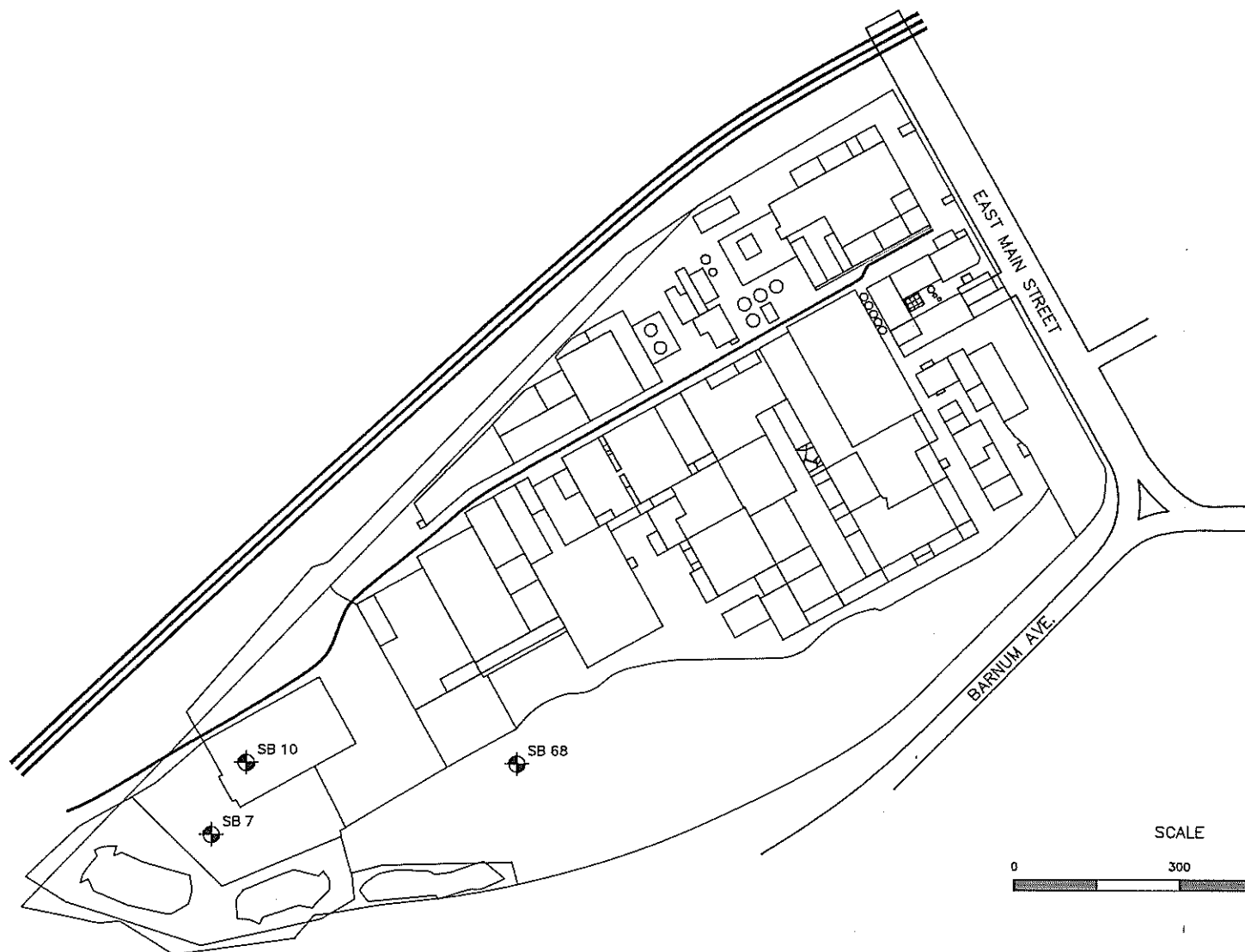
TABLE 1-2
SAMPLES IDENTIFICATION
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT

SAMPLE CODE	ON/OFF SITE	LOCATION	DEPTH (Ft)	TYPE
TS*B-10*1.5-4	On-Site	SB-10	1.5-4	Soil Boring Sample
TS*B-68*2-4	On-Site	SB-68	2-4	Soil Boring Sample
TS*B-68*6-8	On-Site	SB-68	6-8	Soil Boring Sample
TS*B-7*4-6	On-Site	SB-7	4-6	Soil Boring Sample

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1-7



SCALE

0 300 600

LEGEND


 SB SOIL BORING

FIGURE 1-1
ON-SITE TREATABILITY SAMPLES SOIL BORINGS LOCATION
RAYMARK INDUSTRIES SITE
STRATFORD, CONNECTICUT

The bench-scale thermal treatment treatability study was performed by Kiber Environmental Services in coordination with HNUS and in accordance with the Work Plan. The treatability study consisted of three major phases: characterization of the as-received soil-waste materials samples, intermediate testing, and verification testing. As part of the treatability study and with the help of their lower-tier thermal treatment consultant, Four Nines, Inc., Kiber also developed a conceptual design and cost estimates for a full-scale thermal treatment system.

At the conclusion of the treatability study, Kiber prepared a Report to Halliburton NUS on Bench-Scale Low Temperature Thermal Desorption Testing (Kiber Report). This report provided detailed treatability study results as well as design and costing information for the full-scale thermal treatment system. The Kiber Report is included in Appendix B. HNUS expanded the Kiber costing information (which was based on a volume of 300,000 cubic yards) and has included a Cost Sensitivity Analysis Comparison for 300,000, 150,000, and 50,000 cubic yards in Appendix C.

The following sections provide a summary of the treatability study results, and design and costing information for a full-scale thermal treatment system. Additional information on the scope of work and procedures for this treatability study is provided in the Work Plan, which is included as Appendix A.

2.0 SUMMARY OF TESTING RESULTS

2.1 As-Received Samples Characterization

Characterization results for the as-received samples are shown on Tables 2-1 through 2-4. Table 2-1 provides results for PCBs and pesticides. Table 2-2 provides results for other organic constituents including Volatile Organic Compounds (VOCs), Semi-Volatile Organic Compounds (SVOCs), Total Organic Carbon (TOC), and dioxins. Table 2-3 provides results for metals. Table 2-4 summarizes the physical and geotechnical properties of the as-received samples.

Tables 2-1 and 2-3 show that the as-received samples concentrations of PCBs and lead, the main contaminants of concern, were fairly typical of anticipated values. Total PCBs concentrations ranged from approximately 21 to 230 mg/kg, as compared to an anticipated range of 2 to 300 mg/kg. Total lead concentrations ranged from 23 to 15,000 mg/kg, as compared to an anticipated range of 100 to more than 10,000 mg/kg. The as-received samples were therefore shown to be relatively representative of anticipated conditions at the Raymark Industries Site.

Table 2-2 shows that the as-received samples contained relatively low concentrations (0.6 to 290.0 $\mu\text{g/kg}$) of a variety of VOCs, including acetone, benzene, carbon disulfide, chlorobenzene, 1,2-dichloroethene, ethyl benzene, methylene chloride, tetrachloroethene, trichloroethene, and xylenes. It should be noted, however, that it is likely that some of the most significant VOCs concentrations, in particular those of acetone (190 $\mu\text{g/kg}$ max) and methylene chloride (290 $\mu\text{g/kg}$ max) were the result of cross-contamination from laboratory solvents.

Table 2-2 shows that the as-received samples contained moderate concentrations (42 to 20,000 $\mu\text{g/kg}$) of SVOCs including benzo(a)anthracene, benzo(b)fluoranthene, benzo(a)pyrene, chrysene, 2,4-dimethylphenol, fluoranthene, phenanthrene, and pyrene.

Table 2-2 shows that the TOC content of the samples ranged from 1,000 to 40,000 mg/kg and proved to be extremely variable, within a given sample, as demonstrated by sample TS*B-7*4-6, which had a measured as-received TOC of 1,900 mg/kg and 40,000 mg/kg prior to verification testing.

The TOC analysis was performed twice for the untreated samples; once for the as-received samples and once for untreated samples prior to verification testing. The TOC was fairly uniform for the as-received samples, ranging from 1,200 to 2,100 mg/kg. With the exception of TS*B-10*1.5-4, the other three untreated pre-verification samples all had TOC values in the same range (30,000 to 40,000 mg/kg). The variation between the as-received and the untreated pre-verification samples may be attributable to the heterogeneous nature of the samples collected (oily, moist, fibrous material content) and possibly the analysis performed at two separate times (resulting in different moisture content or different analysts). In addition, only 10 grams of specimen were used to represent each sample for the TOC analysis. There can be significant

TABLE 2-1
AS-RECEIVED SAMPLES CHARACTERIZATION
PCBs AND PESTICIDES
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT

PARAMETER ANALYTICAL METHOD	TS*B-10*1.5-4		TS*B-68*2-4		TS*B-68*6-8			TS*B-7*4-6	
	(1)	(2)	(1)	(2)	(1)	(2)	(3)	(1)	(2)
Total Pesticides ($\mu\text{g}/\text{kg}$) SW846-3550/8080									
• Aldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND
• alpha-BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND
• beta-BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND
• delta-BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND
• gamma-BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND
• alpha-Chlordane	ND	ND	ND	ND	ND	ND	ND	ND	ND
• gamma-Chlordane	ND	ND	ND	ND	ND	ND	ND	ND	ND
• 4,4'-DDD	ND	ND	ND	ND	ND	ND	ND	ND	ND
• 4,4'-DDE	ND	ND	ND	ND	ND	ND	ND	ND	ND
• 4,4'-DDT	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Dieldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Endosulfan I	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Endosulfan II	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Endosulfan Sulfate	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Endrin	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Endrin ketone	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Heptachlor	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Heptachlor epoxide	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Methoxychlor	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Toxaphene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total PCBs ($\mu\text{g}/\text{kg}$) SW846-3550/8080									
• Aroclor 1016	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1221	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1232	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1242	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1248	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1254	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1260	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1262	19,000E	18,000E	54,000E	36,000E	96,000E	92,000E	77,000E	140,000E	13,000E
• Aroclor 1268	11,000E	10,000E	35,000E	23,000E	60,000E	56,000E	47,000E	90,000E	8,600

NOTES:

(1): As-received sample

(2): Untreated sample prior to verification testing

(3): Untreated sample prior to additional intermediate testing

ND: Not Detected

E: Estimated Value

TABLE 2-2
AS-RECEIVED SAMPLES CHARACTERIZATION
ORGANIC CONSTITUENTS
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT

PARAMETER ANALYTICAL METHOD	TS*B-10*1.5-4		TS*B-68*2-4		TS*B-68*6-8		TS*B-7*4-6	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Total VOCs ($\mu\text{g}/\text{kg}$) Method SW846-3550/8260								
• Acetone	9.1E	ND	96	ND	190	ND	160	ND
• Benzene	ND	0.6E	ND	ND	6.2E	4.4E	7.1E	1.9E
• Bromodichloromethane	ND	ND	ND	ND	ND	ND	ND	ND
• Bromoform	ND	ND	ND	ND	ND	ND	ND	ND
• Bromomethane	ND	ND	ND	ND	ND	ND	ND	ND
• 2-Butanone (MEK)	ND	ND	ND	ND	ND	ND	ND	ND
• Carbon Disulfide	ND	ND	ND	ND	53	120	17E	33
• Carbon Tetrachloride	ND	ND	ND	ND	ND	ND	ND	ND
• Chlorobenzene	57	1.0E	ND	ND	ND	ND	16	11
• Chloroethane	ND	ND	ND	ND	ND	ND	28E	11
• Chloroform	ND	ND	ND	ND	ND	ND	ND	ND
• Chloromethane	ND	ND	ND	ND	ND	ND	ND	ND
• Dibromochloromethane	ND	ND	ND	ND	ND	ND	ND	ND
• 1,1-Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND
• 1,2-Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND
• 1,1-Dichloroethene	ND	ND	ND	ND	ND	ND	ND	ND
• 1,2-Dichloroethene (total)	12	ND	ND	ND	ND	ND	ND	7.0E
• 1,2-Dichloropropane	ND	ND	ND	ND	ND	ND	ND	ND
• cis-1,2-Dichloropropene	ND	ND	ND	ND	ND	ND	ND	ND
• trans-1,2-Dichloropropene	ND	ND	ND	ND	ND	ND	ND	ND
• Ethylbenzene	2.9E	ND	ND	ND	23E	ND	14E	10
• 2-Hexanone	ND	ND	ND	ND	ND	ND	ND	ND
• Methylene Chloride	6.0E	6.5E	290	130	48E	130	260	150
• 4-Methyl-2-Pentanone (MIBK)	ND	ND	ND	ND	ND	ND	ND	ND
• Styrene	ND	ND	ND	ND	ND	ND	ND	ND
• 1,1,2,2-Tetrachloroethane	ND	ND	ND	ND	ND	ND	ND	ND
• Tetrachloroethene	2.4E	1.8E	ND	ND	ND	ND	ND	ND
• Toluene	4.1	ND	ND	ND	8.1E	8.1E	37	8.9
• 1,1,1-Trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND
• 1,1,2-Trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND
• Trichloroethene	96	56	ND	ND	ND	ND	5.1E	6.5
• Vinyl Acetate	ND	ND	ND	ND	ND	ND	ND	ND
• Vinyl Chloride	ND	ND	ND	ND	ND	ND	ND	ND
• Xylenes (total)	14	ND	ND	ND	35	50	110	60

TABLE 2-2
AS-RECEIVED SAMPLES CHARACTERIZATION
ORGANIC CONSTITUENTS
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT
PAGE TWO OF FOUR

PARAMETER ANALYTICAL METHOD	TS*B-10*1.5-4		TS*B-68*2-4		TS*B-68*6-8		TS*B-7*4-6	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Total SVOCs ($\mu\text{g}/\text{kg}$)								
Method SW846-3550/8270								
• Acenaphthene	ND	ND	ND	ND	ND	ND	870	ND
• Acenaphthylene	ND	ND	440E	ND	ND	ND	1,100	ND
• Anthracene	ND	ND	410E	ND	210E	ND	1,400	ND
• Benzo(a)anthracene	ND	ND	1,700	1,100E	460E	ND	2,700	3,100E
• Benzo(b)fluoranthene	42E	ND	4,700	2,000E	910	ND	4,300	4,800E
• Benzo(k)fluoranthene	ND	ND	ND	ND	ND	ND	1,200	ND
• Benzoic Acid	ND	ND	ND	ND	ND	ND	ND	ND
• Benzo(g,h,i)perylene	ND	ND	ND	ND	ND	ND	1,600	ND
• Benzo(a)pyrene	ND	ND	2,200	1,200E	350E	ND	2,900	ND
• Benzyl Alcohol	ND	ND	ND	ND	ND	ND	ND	ND
• bis(2-Chloroethoxy)methane	ND	ND	ND	ND	ND	ND	ND	ND
• bis(2-Chloroethyl)ether	ND	ND	ND	ND	ND	ND	ND	ND
• bis(2-Chloroisopropyl)ether	ND	ND	ND	ND	ND	ND	ND	ND
• bis(2-Ethylhexyl)phthalate	550	510	280E	ND	440E	ND	520E	ND
• 4-Bromophenyl-phenylether	ND	ND	ND	ND	ND	ND	ND	ND
• Butylbenzylphthalate	ND	ND	ND	ND	ND	ND	ND	ND
• 4-Chloroaniline	ND	ND	ND	ND	ND	ND	ND	ND
• 4-Chloro-2-methylphenol	ND	ND	ND	ND	ND	ND	ND	ND
• 2-Chloronaphthalene	ND	ND	ND	ND	ND	ND	ND	ND
• 2-Chlorophenol	ND	ND	ND	ND	ND	ND	ND	ND
• 4-Chlorophenyl-phenylether	ND	ND	ND	ND	ND	ND	ND	ND
• Chrysene	ND	ND	2,500	1,400E	420E	ND	2,700	3,200E
• Dibenzo(a,h)anthracene	ND	ND	ND	ND	ND	ND	430E	ND
• Dibenzofuran	ND	ND	ND	ND	ND	ND	1,100	ND
• Di-n-butylphthalate	150	27E	ND	ND	ND	ND	ND	ND
• 1,2-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND
• 1,3-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND
• 1,4-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND
• 3,3'-Dichlorobenzidine	ND	ND	500E	ND	2,800	ND	ND	ND
• 2,4-Dichlorophenol	ND	ND	ND	ND	ND	ND	ND	ND
• Diethylphthalate	ND	ND	ND	ND	ND	ND	ND	ND
• 2,4-Dimethylphenol	280	55E	ND	ND	380E	ND	20,000	20,000
• Dimethylphthalate	ND	ND	ND	ND	ND	ND	1,400	ND
• 4,6-Dinitro-2-methylphenol	ND	ND	ND	ND	ND	ND	ND	ND

TABLE 2-2
AS-RECEIVED SAMPLES CHARACTERIZATION
ORGANIC CONSTITUENTS
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT
PAGE THREE OF FOUR

PARAMETER ANALYTICAL METHOD	TS*B-10*1.5-4		TS*B-68*2-4		TS*B-68*6-8		TS*B-7*4-6	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Total SVOCs (Continued)(µg/kg) Method SW846-3550/8270								
• 2,4-Dinitrophenol	ND	ND	ND	ND	ND	ND	ND	ND
• 2,4-Dinitrotoluene	ND	ND	ND	ND	ND	ND	ND	ND
• 2,6-Dinitrotoluene	ND	ND	ND	ND	ND	ND	ND	ND
• Di-n-octylphthalate	ND	ND	ND	ND	ND	ND	ND	ND
• Fluoranthene	ND	ND	3,500	2,200	780	900E	6,000	5,900E
• Fluorene	ND	ND	220E	ND	270E	ND	2,100	ND
• Hexachlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND
• Hexachlorobutadiene	ND	ND	ND	ND	ND	ND	ND	ND
• Hexachlorocyclopentadiene	ND	ND	ND	ND	ND	ND	ND	ND
• Hexachloroethane	ND	ND	ND	ND	ND	ND	ND	ND
• Indeno(1,2,3-cd)pyrene	ND	ND	780	ND	ND	ND	1,200	ND
• Isophorone	ND	ND	ND	ND	ND	ND	ND	ND
• 2-Methylnaphtalene	64E	ND	ND	ND	760E	ND	2,000	ND
• 2-Methylphenol	ND	ND	ND	ND	ND	ND	880E	ND
• 3,4-Methylphenol	730	130	ND	ND	ND	ND	7,100	3,800E
• Naphtalene	42E	ND	ND	ND	880E	ND	2,000	ND
• 2-Nitroaniline	ND	ND	ND	ND	ND	ND	ND	ND
• 3-Nitroaniline	ND	ND	ND	ND	ND	ND	ND	ND
• 4-Nitroaniline	ND	ND	ND	ND	ND	ND	ND	ND
• Nitrobenzene	ND	ND	ND	ND	ND	ND	ND	ND
• 2-Nitrophenol	110	ND	ND	ND	ND	ND	ND	ND
• 4-Nitrophenol	620E	ND	ND	ND	ND	ND	ND	ND
• N-Nitrosodiphenylamine	ND	ND	ND	ND	770E	ND	830E	ND
• N-Nitroso-di-n-propylamine	ND	ND	ND	ND	ND	ND	ND	ND
• Pentachlorophenol	ND	ND	ND	ND	ND	ND	ND	ND
• Phenantrene	92	ND	2,300	1,100E	1,200	1,000E	5,900	5,500E
• Phenol	ND	ND	ND	ND	ND	ND	ND	ND
• Pyrene	ND	ND	3,500	2,100E	890	1,200E	5,700	6,400E
• 1,2,4-Trichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND
• 2,4,5-Trichlorophenol	ND	ND	ND	ND	ND	ND	ND	ND
• 2,4,6-Trichlorophenol	ND	ND	ND	ND	ND	ND	ND	ND
TOC (mg/kg) SW846-3550/9060	2,100	1,000	1,200	30,000	1,900	38,000	1,900	40,000

TABLE 2-2
AS-RECEIVED SAMPLES CHARACTERIZATION
ORGANIC CONSTITUENTS
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT
PAGE FOUR OF FOUR

PARAMETER ANALYTICAL METHOD	TS*B-10*1.5-4		TS*B-68*2-4		TS*B-68*6-8		TS*B-7*4-6	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Dioxins ($\mu\text{g/kg}$) SW846-3550/8280								
• Total TCDD	ND	NA	ND	NA	ND	NA	ND	NA
• Total PeCDD	ND	NA	ND	NA	ND	NA	ND	NA
• Total HxCDD	ND	NA	ND	NA	ND	NA	ND	NA
• Total HpCDD	ND	NA	ND	NA	ND	NA	ND	NA
• Total TCDF	ND	NA	ND	NA	ND	NA	1.3	NA
• Total PeCDF	ND	NA	2.3	NA	ND	NA	3.5	NA
• Total HxCDF	ND	NA	16	NA	17	NA	25	NA
• Total HpCDF	ND	NA	8.9	NA	ND	NA	11	NA

NOTES:

- (1): As-received sample
 (2): Untreated sample prior to verification testing
 E: Estimated Values
 ND: Not Detected
 NA: Not Analyzed

TABLE 2-3
AS-RECEIVED SAMPLES CHARACTERIZATION
METALS
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT

PARAMETER ANALYTICAL METHOD	TS*B-10*1.5-4		TS*B-68*2-4		TS*B-68*6-8		TS*B-7*4-6	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Total Metals (mg/kg) Method SW846-6010/7471								
• Arsenic	ND	ND	ND	ND	ND	ND	ND	ND
• Barium	34	41	3,900	2,200	2,400	1,400	2,200	1,800
• Cadmium	ND	ND	0.49E	ND	ND	0.39E	2.3	1.2E
• Chromium	6.2E	7.5E	85	40	47	63	69	69
• Lead	23	30	8,800	4,000	11,000	13,000	15,000	14,000
• Mercury	ND	ND	ND	ND	ND	ND	ND	ND
• Selenium	ND	ND	ND	ND	ND	ND	ND	ND
• Silver	0.56E	0.74E	1.6E	0.89E	1.3E	1.3E	2.5	2.5

NOTES:

- (1): As-received sample
(2): Untreated sample prior to verification testing
E: Estimated Values

TABLE 2-4
AS-RECEIVED SAMPLES CHARACTERIZATION
PHYSICAL AND GEOTECHNICAL PARAMETERS
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT

PARAMETER	TS*B-10*1.5-4	TS*B-68*2-4	TS*B-68*6-8	TS*B-7*4-6
Description	Coarse sand to gravel with small rocks. Reddish brown. Fairly moist.	Fine sand to gravel w/ small clay chunks. Brown. Very moist.	Sand with rubber-like material. Black. Moist.	Clay-like with gravel, straw, and fibrous matter. Black. Moist and oily.
pH (SU)	6.65	5.58	6.00	6.38
Moisture Content (%) • As-Received • Before Final Testing	4.10 3.74	18.11 18.73	37.02 45.44	47.44 52.11
Bulk Unit Weight (lbs/ft³)	119.7	111.1	104.8	108.6
Dry Unit Weight (lbs/ft³)	115.0	94.1	76.5	73.6
Particle Size Distribution • Mean Size (1) (microns) • Effective Size (2) (microns) • Larger than 1-inch (% by wt)	1,300 300 29	350 40 5	400 12 4	1,000 15 21

NOTES:

- (1): Mean Size is the size 50 percent of the particles, by weight of a sample, are either smaller or larger than
(2): Effective Size is the size 90 percent, by weight of a sample, of the particles are larger than

variability in a specimen obtained from a 5-gallon container. Table 2-2 also shows that dibenzofurans were detected in three of the as-received samples.

Table 2-4 shows that all as-received samples, except TS*B-10*1.5-4, had a significant moisture content, ranging up to 52 percent by weight. Table 2-4 also shows that samples TS*B-10*1.5-4 and TS*B-7*4-6 had up to 29 percent of material larger than 1 inch which would have to be considered off-sized and would need to be screened-off before treatment with several types of thermal treatment systems. Samples TS*B-68*6-8 and TS*B-7*4-6 were also shown to contain significant amounts of foreign materials (oil, straw, fibers).

2.2 Intermediate Testing

Based on the results of the as-received samples characterization and on typical operating parameters for full-scale thermal treatment systems, initial intermediate tests were performed on each of the four as-received samples in accordance with the following matrix:

TEMPERATURE (°F)	DETENTION TIME (Minutes)		
	10	20	40
700	X	X	X
1,000	X	X	X
1,200	X	X	X

Following this initial round of intermediate tests, additional intermediate tests were performed for sample TS*B-68*6-8. This sample was selected for additional testing since the first round intermediate testing results indicated difficulty in reducing PCB concentrations at the specified residence times. Increased residence times of 60 and 90 minutes at 1000 degrees F, and 60, 75, and 90 residence minutes at 1200 degrees F were used. This sample was tested at 1,000 degrees F and 60 and 90 minutes detention times and at 1,200 degrees F and 60, 75, and 90 minutes detention times.

Results of the intermediate tests are shown on Tables 2-5 through 2-8. Tables 2-5 through 2-7 provide PCBs concentrations for samples tested at 700 degrees F, 1,000 degrees F, and 1,200 degrees F, respectively. Table 2-8 summarizes the percentages of PCBs removal obtained by the various intermediate testing conditions.

When considering the PCB removal percentages shown on Table 2-8, variations (decrease or increase) of less than 50 percent in PCBs concentration cannot be considered significant since, because of the heterogeneity of the soil medium, these variations probably fall within the expected analytical scatter for a given sample.

TABLE 2-5
INTERMEDIATE TESTING RESULTS
700 °F (371 °C)
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT

PARAMETER	DETENTION TIME (Minutes)											
	TS*B-10*1.5-4			TS*B-68*2-4			TS*B-68*6-8			TS*B-7*4-6		
	10	20	40	10	20	40	10	20	40	10	20	40
Total PCBs ($\mu\text{g}/\text{kg}$) SW-846-3550/8080												
• Aroclor 1061	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1221	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1232	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1242	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1248	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1254	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1260	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1262	27,000E	37,000E	1,600E	57,000E	57,000E	35,000E	160,000E	190,000E	150,000E	120,000E	140,000E	110,000E
• Aroclor 1268	12,000E	21,000E	900E	34,000E	32,000E	20,000E	84,000E	100,000E	83,000E	65,000E	85,000E	64,000E

NOTES:

ND: Not Detected

E: Value estimated due to overlapping of chromatography peaks requiring estimation from analytical chemist

TABLE 2-6
INTERMEDIATE TESTING RESULTS
1,000 °F (538 °C)
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT

PARAMETER	DETENTION TIME (Minutes)													
	TS*B-10*1.5-4			TS*B-68*2-4			TS*B-68*6-8					TS*B-7*4-6		
	10	20	40	10	20	40	10	20	40	60	90	10	20	40
Total PCBs (µg/kg) SW-846-3550/8080														
• Aroclor 1061	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1221	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1232	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1242	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1248	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1254	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1260	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1262	4,500E	360E	ND	33,000E	28,000E	160E	150,000E	130,000E	110,000E	ND	ND	110,000E	280,000E	44E
• Aroclor 1268	2,300E	170E	ND	19,000E	16,000E	36E	82,000E	73,000E	46,000E	ND	ND	61,000E	170,000E	ND

NOTES:

ND: Not Detected

E: Estimated value due to overlapping of chromatography peaks requiring estimation from analytical chemist

TABLE 2-7
INTERMEDIATE TESTING RESULTS
1,200 °F (649 °C)
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT

PARAMETER	DETENTION TIME (Minutes)														
	TS*B-10*1.5-4			TS*B-68*2-4			TS*B-68*6-8						TS*B-7*4-6		
	10	20	40	10	20	40	10	20	40	60	75	90	10	20	40
Total PCBs (µg/kg) SW-846-3550/8080															
• Aroclor 1061	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1221	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1232	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1242	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1248	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1254	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1260	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
• Aroclor 1262	3,200E	ND	ND	45,000E	19,000E	ND	170,000E	140,000E	3,200E	ND	ND	ND	160,000E	160,000E	ND
• Aroclor 1268	1,400E	ND	ND	21,000E	8,100E	ND	91,000E	77,000E	1,000E	ND	ND	ND	94,000E	93,000E	ND

NOTES:

ND: Not Detected

E: Estimated value due to overlapping of chromatography peaks requiring estimation from analytical chemist

TABLE 2-8
INTERMEDIATE TESTING RESULTS
SUMMARY OF PCBs REMOVAL PERCENTAGES
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STARTFORD, CONNECTICUT

SAMPLES	700°F		1,000°F		1,200°F	
	DETENTION TIME (Minutes)	PCB REMOVAL (%)	DETENTION TIME (Minutes)	PCB REMOVAL (%)	DETENTION TIME (Minutes)	PCB REMOVAL (%)
TS*B-10*1.5-4	10	0 (+30)	10	77	10	85
	20	0 (+93)	20	98	20	99
	40	92	40	99	40	99
TS*B-68*2-4	10	0 (+2)	10	42	10	26
	20	0	20	51	20	70
	40	38	40	99	40	99
TS*B-68*6-8	10	0 (+56)	10	0 (+49)	10	0 (+67)
	20	0 (+86)	20	0 (+30)	20	0 (+39)
	40	0 (+49)	40	0	40	97
	60	NT	60	99	60	99
	75	NT	75	NT	75	99
	90	NT	90	99	90	99
TS*B-7*4-6	10	19	10	26	10	10
	20	2	20	0 (+96)	20	10
	40	24	40	99	40	99

NOTES:

- Shaded results indicate that the 2.0 mg/kg total PCB concentration objective has been met
- Positive figures in parenthesis next to zero percent removal results indicate an actual percentage increase.

Tables 2-5 and 2-8 show that at 700 degrees F, no significant removal of PCBs occurred with detention times of up to 40 minutes, except for sample TS*B-10*1.5-4, which showed a removal of about 90 percent with a 40-minute detention time.

Tables 2-6 and 2-8 show that, at 1,000 degrees F, the target total PCB concentration of 2.0 mg/kg or less was achieved with 40 minutes detention time for all samples except TS*B-68*6-8. Sample TS*B-68*6-8 showed no significant PCB removal at 1,000 degrees F for detention times of up to 40 minutes but showed essentially complete PCB removal for detention times of 60 and 90 minutes. Table 2-7 and 2-8 show that, at 1,200 degrees F, complete removal of PCBs is achieved with 20 and 40 minutes detention times for sample TS*B-10*1.5-4, and with 40 minutes detention time for samples TS*B-68*2-4, and TS*B-7*4-6. For sample TS*B-68*6-8, a detention time of 40 minutes at 1,200 degrees F achieved a PCBs concentration of 4.2 mg/kg, just short of the target of 2.0 mg/kg, and 60 minutes or more detention time was required to achieve the necessary PCB removal.

During intermediate testing, sample TS*B-7*4-6 was observed to flame as the result of combustion when treated at 1000 degrees F or higher. HNUS assumes that the flames were caused in part by the presence of oils, fibrous materials, and rubber-like materials in the samples. In addition, there may have been other materials, such as resins, used in brake manufacturing that could have combusted at the elevated temperatures. Nitrogen gas was used to continuously purge the furnace to prevent soil waste combustion.

Figure 2-1 presents a graphical depiction of the correlation between the maximum soil temperature achieved during treatment and the concentrations of PCBs remaining in the treated soils.

Based on the results of the intermediate tests and a comparison of the temperature versus PCBs remaining, it was determined that final testing would be at a temperature of 1,000 degrees F with a detention time of 60 minutes for the verification testing. Purging with nitrogen gas was also selected for the verification testing phase to prevent soil waste combustion.

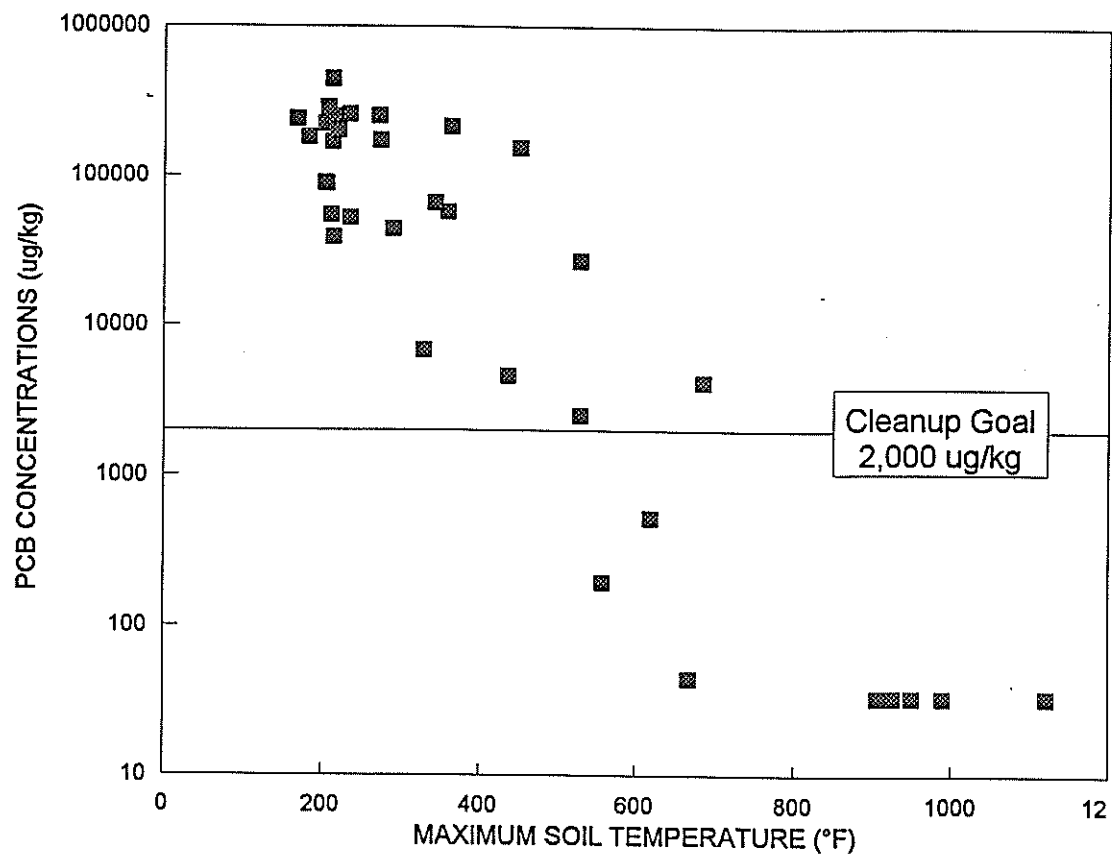
2.3 Verification Testing

Verification testing was performed with all four samples at 1,000°F with a detention time of 60 minutes. Results of the verification testing are shown on Tables 2-9 through 2-11. Table 2-9 provides results for PCBs and pesticides.

Table 2-10 provides results for other organic constituents, including VOCs, SVOCs, TOC, and dioxins. Table 2-11 provides results for metals.

The analytical results shown on Table 2-9 confirm that a temperature of 1,000 degrees F and a detention time of 60 minutes are adequate to remove all detectable PCBs from the soil-waste materials at the Raymark Industries Site and to meet the target PCB concentration of 2.0 mg/kg or less.

FIGURE 2-1
SOIL TEMPERATURE VS. PCB CONCENTRATION
RAYMARK INDUSTRIES SITE
STRATFORD, CONNECTICUT



SZ592/854_230

TABLE 2-9
VERIFICATION TESTING¹ RESULTS
PCBs AND PESTICIDES
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT

PARAMETER ANALYTICAL METHOD	TS*B-10*1.5-4	TS*B-68*2-4	TS*B-68*6-8	TS*B-7*4-6
Total Pesticides ($\mu\text{g}/\text{kg}$) SW846-3550/8080				
● Aldrin	ND	ND	ND	ND
● alpha-BHC	ND	ND	ND	ND
● beta-BHC	ND	ND	ND	ND
● delta-BHC	ND	ND	ND	ND
● gamma-BHC	ND	ND	ND	ND
● alpha-Chlordane	ND	ND	ND	ND
● gamma-Chlordane	ND	ND	ND	ND
● 4,4'-DDD	ND	ND	ND	ND
● 4,4'-DDE	ND	ND	ND	ND
● 4,4'-DDT	ND	ND	ND	ND
● Dieldrin	ND	ND	ND	ND
● Endosulfan I	ND	ND	ND	ND
● Endosulfan II	ND	ND	ND	ND
● Endosulfan Sulfate	ND	ND	ND	ND
● Endrin	ND	ND	ND	ND
● Endrin ketone	ND	ND	ND	ND
● Heptachlor	ND	ND	ND	ND
● Heptachlor epoxide	ND	ND	ND	ND
● Methoxychlor	ND	ND	ND	ND
● Toxaphene	ND	ND	ND	ND
Total PCBs ($\mu\text{g}/\text{kg}$) SW846-3550/8080				
● Aroclor 1016	ND	ND	ND	ND
● Aroclor 1221	ND	ND	ND	ND
● Aroclor 1232	ND	ND	ND	ND
● Aroclor 1242	ND	ND	ND	ND
● Aroclor 1248	ND	ND	ND	ND
● Aroclor 1254	ND	ND	ND	ND
● Aroclor 1260	ND	ND	ND	ND
● Aroclor 1262	ND	ND	ND	ND
● Aroclor 1268	ND	ND	ND	ND

NOTES:

ND: Non Detected

1: Testing conducted at 1,000°F and 60 minute detection time.

TABLE 2-10
VERIFICATION TESTING RESULTS
ORGANIC CONSTITUENTS
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT

PARAMETER ANALYTICAL METHOD	TS*B-10*1.5-4	TS*B-68*2-4	TS*B-68*6-8	TS*B-7*4-6
Total VOCs (µg/kg) Method SW846-3550/8260				
• Acetone	16	ND	ND	ND
• Benzene	0.7E	21E	540	65/37E
• Bromodichloromethane	ND	ND	ND	ND
• Bromoform	ND	ND	ND	ND
• Bromomethane	ND	ND	ND	ND
• 2-Butanone (MEK)	27E	780E	ND	800E/740E
• Carbon Disulfide	ND	ND	ND	ND
• Carbon Tetrachloride	ND	ND	ND	ND
• Chlorobenzene	ND	ND	150	ND
• Chloroethane	ND	ND	ND	ND
• Chloroform	ND	ND	ND	ND
• Chloromethane	ND	ND	ND	92E/ND
• Dibromochloromethane	ND	ND	ND	ND
• 1,1-Dichloroethane	ND	ND	ND	ND
• 1,2-Dichloroethane	ND	ND	ND	ND
• 1,1-Dichloroethene	ND	ND	ND	ND
• 1,2-Dichloroethene (total)	ND	ND	ND	ND
• 1,2-Dichloropropane	ND	ND	ND	ND
• cis-1,2-Dichloropropene	ND	ND	ND	ND
• trans-1,2-Dichloropropene	ND	ND	ND	ND
• Ethylbenzene	1.4E	ND	ND	ND
• 2-Hexanone	ND	ND	ND	ND/160E
• Methylene Chloride	28	400E	2,100	560/800
• 4-Methyl-2-Pentanone (MIBK)	ND	ND	ND	ND
• Styrene	ND	ND	ND	ND
• 1,1,2,2-Tetrachloroethane	ND	ND	ND	ND
• Tetrachloroethene	1.9E	ND	ND	ND
• Toluene	ND	ND	93E	ND
• 1,1,1-Trichloroethane	ND	ND	ND	ND
• 1,1,2-Trichloroethane	ND	ND	ND	ND
• Trichloroethene	ND	ND	ND	ND
• Vinyl Acetate	ND	ND	ND	ND
• Vinyl Chloride	ND	ND	ND	ND
• Xylenes (total)	7.7	ND	33E	32E/41E
Total SVOCs (µg/kg) Method SW846-3550/8270				
• Acenaphthene	ND	ND	ND	ND
• Acenaphthylene	ND	ND	ND	ND
• Anthracene	ND	ND	ND	ND
• Benzo(a)anthracene	ND	ND	ND	ND
• Benzo(b)fluoranthene	ND	ND	ND	ND
• Benzo(k)fluoranthene	ND	ND	ND	ND
• Benzoic Acid	ND	ND	ND	ND
• Benzo(g,h,i)perylene	ND	ND	ND	ND
• Benzo(a)pyrene	ND	ND	ND	ND
• Benzyl Alcohol	ND	ND	ND	ND
• bis(2-Chloroethoxy)methane	ND	ND	ND	ND
• bis(2-Chloroethyl)ether	ND	ND	ND	ND
• bis(2-Chloroisopropyl)ether	ND	ND	ND	ND
• bis(2-Ethylhexyl)phtalate	ND	ND	ND	ND/800
• 4-Bromophenyl-phenylether	ND	ND	ND	ND
• Butylbenzylphtalate	ND	ND	ND	ND
• 4-Chloroaniline	ND	ND	ND	ND
• 4-Chloro-2-methylphenol	ND	ND	ND	ND

TABLE 2-10
VERIFICATION TESTING RESULTS
ORGANIC CONSTITUENTS
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT
PAGE TWO OF THREE

PARAMETER ANALYTICAL METHOD	TS*B-10*1.5-4	TS*B-68*2-4	TS*B-68*6-8	TS*B-7*4-6
Total SVOCs (µg/kg)(Continued)				
Method SW846-3550/8270				
• 2-Chloronaphtalene	ND	ND	ND	ND
• 2-Chlorophenol	ND	ND	ND	ND
• 4-Chlorophenyl-phenylether	ND	ND	ND	ND
• Chrysene	ND	ND	ND	ND
• Dibenzo(a,h)anthracene	ND	ND	ND	ND
• Dibenzofuran	ND	ND	ND	ND
• Di-n-butylphthalate	ND	ND	ND	ND
• 1,2-Dichlorobenzene	ND	ND	ND	27E
• 1,3-Dichlorobenzene	ND	ND	ND	ND
• 1,4-Dichlorobenzene	ND	ND	ND	ND
• 3,3'-Dichlorobenzidine	ND	ND	ND	ND
• 2,4-Dichlorophenol	ND	ND	ND	ND
• Diethylphthalate	ND	ND	ND	ND
• 2,4-Dimethylphenol	ND	ND	ND	ND
• Dimethylphthalate	ND	ND	ND	ND
• 4,6-Dinitro-2-methyphenol	ND	ND	ND	ND
• 2,4-Dinitrophenol	ND	ND	ND	ND
• 2,4-Dinitrotoluene	ND	ND	ND	ND
• 2,6-Dinitrotoluene	ND	ND	ND	ND
• Di-n-octylphthalate	ND	ND	ND	ND
• Fluoranthene	ND	ND	ND	ND
• Fluorene	ND	ND	ND	ND
• Hexachlorobenzene	ND	ND	ND	ND
• Hexachlorobutadiene	ND	ND	ND	ND
• Hexachlorocyclopentadiene	ND	ND	ND	ND
• Hexachloroethane	ND	ND	ND	ND
• Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND
• Isophorone	ND	ND	ND	ND
• 2-Methylnaphtalene	ND	ND	ND	ND
• 2-Methylphenol	ND	ND	ND	ND
• 3,4-Methylphenol	ND	ND	ND	ND
• Naphtalene	ND	ND	ND	ND
• 2-Nitroaniline	ND	ND	ND	ND
• 3-Nitroaniline	ND	ND	ND	ND
• 4-Nitroaniline	ND	ND	ND	ND
• Nitrobenzene	ND	ND	ND	ND
• 2-Nitrophenol	ND	ND	ND	ND
• 4-Nitrophenol	ND	ND	ND	ND
• N-Nitrosodiphenylamine	ND	ND	ND	ND
• N-Nitroso-di-n-propylamine	ND	ND	ND	ND
• Pentachlorophenol	ND	ND	ND	ND
• Phenantrene	ND	ND	ND	ND
• Phenol	ND	ND	ND	ND
• Pyrene	ND	ND	ND	ND
• 1,2,4-Trichlorobenzene	ND	ND	ND	ND
• 2,4,5-Trichlorophenol	ND	ND	ND	ND
• 2,4,6-Trichlorophenol	ND	ND	ND	ND
TOC (mg/kg)				
SW846-3550/9060	ND	6,100	35,000	38,000/28,000

TABLE 2-10
VERIFICATION TESTING RESULTS
ORGANIC CONSTITUENTS
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT
PAGE THREE OF THREE

PARAMETER ANALYTICAL METHOD	TS*B-10*1.5-4	TS*B-68*2-4	TS*B-68*6-8	TS*B-7*4-6
Dioxins ($\mu\text{g/kg}$) SW846-3550/8280				
• Total TCDD	ND	ND	ND	ND
• Total PeCDD	ND	ND	ND	ND
• Total HxCDD	ND	ND	ND	ND
• Total HpCDD	ND	ND	ND	ND
• Total TCDF	ND	ND	ND	ND
• Total PeCDF	ND	ND	ND	ND
• Total HxCDF	ND	ND	ND	ND
• Total HpCDF	ND	ND	ND	ND

NOTES:

Two reported values indicate duplicate samples

E: Estimated Values

ND: Not Detected

TABLE 2-11
VERIFICATION TESTING RESULTS
METALS
THERMAL TREATMENT TREATABILITY STUDY
RAYMARK INDUSTRIES SITE, STRATFORD, CONNECTICUT

PARAMETER ANALYTICAL METHOD	TS*B-10*1.5-4	TS*B-68*2-4	TS*B-68*6-8	TS*B-7*4-6
Total Metals (mg/kg) Method SW846-6010/7471				
● Arsenic	ND	ND	ND	ND
● Barium	37	1,100	830	670/820
● Cadmium	ND	0.47E	0.75E	1.8/1.3
● Chromium	4.9E	49	68	75/56
● Lead	35	6,300	17,000	18,000/9,200
● Mercury	ND	ND	ND	ND
● Selenium	ND	ND	ND	ND
● Silver	0.44E	0.80E	1.5	2.8/2.1

NOTES:

ND: Not Detected
E: Estimated Value

The analytical results shown on Table 2-10 indicate the presence of VOCs in the soil-waste materials in both the as-received and treated samples. Some of the VOCs (acetone, methylene chloride) detected in the treated samples may have resulted from cross-contamination with common laboratory solvents, which could occur before as well as after thermal treatment. All VOCs would be thermally volatilized at the temperatures used during testing, and with adequate agitation. Additional VOCs detected in the treated samples may have been present as the result of cross-contamination by other samples that were analyzed or were present in the laboratory that day. Since no blanks were prepared for analysis, this route of cross-contamination is only hypothesized and cannot be confirmed.

The analytical results shown in Table 2-10 indicate that the thermal treatment process reduces SVOC concentrations from the soil-waste materials to below detection analytical limits. At the 1000 degrees F verification test temperature, all SVOCs are anticipated to be desorbed.

The TOC values appeared to have increased from the as-received and pre-verification stages to the post-treatment stage; however, this increase appears to be the result of how the TOC values were calculated. The TOC values for the as-received and pre-verification samples are calculated using the wet weight of the samples (dry weight of materials, organic compounds, and moisture). In the thermal treatment process, all moisture and numerous carbon compounds are desorbed. The carbon remaining in the treated soil-waste material is present as fixed carbon (char). The TOC for the treated sample is calculated using the dry weight of the samples since the thermal treatment removes most of the moisture and a number of the organic constituents. The apparent TOC increases are likely the result of taking the ratio of organic carbon mass remaining to the mass of the treated sample (in effect only the dry weight); a proportionally higher total carbon content was measured in the treated sample.

Table 2-10 presents the sample TOC values for the as-received and verification analyses. A quick review of the as-received and verification test data suggests that the apparent increase of TOC may be attributable to the initial moisture content as presented in the table below (i.e. low initial moisture results in low apparent TOC change).

Sample Number	Apparent TOC Increase	Initial Moisture Content
TS*B-10*1.5-4	No change	4.1%
TS*B-68*2-4	5 X	18.1%
TS*B-68*6-8	18.4 X	37%
TS*B-7*4-6	20 X	47.4%

Comparison of the verification testing dioxin/furan results with the as-received dioxin/furan results indicates a reduction in the furan concentrations to below detection limits. No dioxins were detected in any sample.

The analytical results shown on Table 2-11 indicate that the total concentrations of metals in the soil-waste materials were essentially unaffected by the thermal treatment process.

3.0 FULL-SCALE THERMAL TREATMENT SYSTEM

The following design and cost estimates are based on the anticipated on-site thermal treatment of approximately 300,000 cubic yards (about 450,000 tons) of soil-waste materials at the Raymark Industries Site. At the RPM's request, additional cost estimates were developed for soil-waste volumes of 150,000 and 50,000 cubic yards. A description of the thermal treatment technology is provided in the Work Plan, which is included as Appendix A. Additional design and cost information is provided in the Kiber Report, which is included as Appendix B.

3.1 Conceptual Thermal Treatment System Design

3.1.1 Thermal Treatment System Type Selection

By design, thermal treatment systems basically fall into two types:

- Systems that desorb organic constituents and incinerate the volatilized organics in a secondary combustion chamber (SCC) for off-gas treatment.
- Systems that desorb organic constituents and condense the volatilized organics for further treatment and/or disposal for off-gas treatment.

Thermal treatment systems of the desorber-incinerator type are generally direct-fired units derived from commercial asphalt production equipment that has been modified to treat CERCLA/RCRA waste materials by boosting operating temperature and upgrading off-gas control devices. For the purpose of this report, the term "direct-fired" means that process air is directly heated and then forced through the treatment unit to volatilize contaminants from the soils. There is no open flame within the reaction chamber. Accordingly, high-capacity thermal treatment systems of this type are readily available and the capital cost is relatively low. Operating and maintenance costs of this type of thermal treatment system are generally moderate.

Thermal treatment systems of the desorber-condenser type are generally indirect-fired, custom-designed, proprietary units such as the Chem Waste Management/Rust Remedial Services X*TRAX system and the Roy F. Weston LT³ system. Accordingly, the availability and capacity of this type of thermal treatment system are more limited and the capital cost is higher than for the desorber-incinerator type of thermal treatment system. Operating and maintenance costs for the desorber-condenser type of thermal treatment system are generally moderate to high.

Three considerations (operating capacity, design detention time, and cost) have led to the tentative selection of a desorber-incinerator type of thermal treatment system for this conceptual design.

Operating Capacity

Because of the large quantities of soil-waste materials to be treated at the Raymark Industries Site, operating capacity is an important consideration if the remedial action is to be completed within a reasonable time frame (2 to 3 years). Thermal treatment systems of the desorber-incinerator type are readily available, with an operating capacity of 40 tons per hour which would meet the time frame objective; the maximum reported operating capacity of thermal treatment systems of the desorber-condenser type is about 7.5 tons per hour, which would require 9 to 10 years to complete the Remedial Action.

Design Detention Time

The direct-fired desorber of the desorber-incinerator thermal treatment systems allows for much shorter design detention times than their indirect-fired counterpart because of their more effective heat transfer. As a result, even though bench-scale testing (performed with an indirect-fired muffle furnace) showed that a detention time of 60 minutes is required for some of the soil-waste materials, the detention time of the direct-fired desorber thermal treatment system for this conceptual design has been selected as 15 minutes, based on previous systems designed by Kiber/Four Nines.

Cost

As previously mentioned, the capital and operating and maintenance costs of the direct-fired desorber-incinerator thermal treatment systems are lower than those of the indirect-fired desorber-condenser systems. This difference, coupled with higher productivity and a much shorter anticipated project duration, makes a direct-fired desorber-incinerator thermal treatment system far more cost-effective than an indirect-fired desorber-condenser thermal treatment system.

3.1.2 Design Assumptions

The following assumptions were made for the conceptual design of the full-scale thermal treatment system:

- The PCBs and dioxin content of the feedstock will be such that the thermal treatment system will not be subject to TSCA requirements.
- The total organic content of the feedstock will not be greater than 2 percent by weight to keep the off-gas from the desorber below 25 percent of the lower explosivity limit (LEL).
- The thermal treatment system will be able to handle soil-waste materials particle sizes of up to 2 inches to avoid excessive quantities of off-size materials that would have to be treated and/or disposed of by other means.

- The cohesive nature of several of the samples, in particular TS*B-68*6-8 and TS*B-7*4-6, will require that belt conveyors and chutes be used within the thermal treatment system rather than screw conveyors for the feed and transfer of the soil-waste materials. This cohesive nature will also require that the desorber unit be designed to maximize heat transfer efficiency.
- The metals content of the soil-waste materials will remain with the treated material (ashes) to the extent where an thermal treatment off-gas treatment system consisting of a cyclone separator, a quench tower, and a bag house will meet Boiler and Industrial Furnace (BIF) and RCRA metals emissions requirements, particularly for lead and chromium.

3.1.3 Design Criteria

The conceptual design criteria for the full-scale thermal treatment system may be summarized as follows:

CRITERIA	DESIGN VALUE
Capacity (tons/hour)	40
Operating Schedule (hours/day)	24
Feedstock Composition: <ul style="list-style-type: none"> • Maximum Total Organic Content (% by wt) • Maximum Particle Size (inches) 	2 2
Operating Parameters: <ul style="list-style-type: none"> • Minimum Desorber Temperature (°F) • Minimum Desorber Detention Time (minutes) • Minimum SCC Temperature (°F) • Minimum SCC Detention Time (seconds) 	900 15 1,800 1
Performance: <ul style="list-style-type: none"> • POHC Destruction & Removal Efficiency (DRE) (%) • Maximum PCBs Concentration in Treated Soil (mg/kg) 	99.99 2.0

3.2 Conceptual Thermal Treatment System Description

The following description is typical of the direct-fired desorber-incinerator type of thermal treatment system that has been selected for this conceptual design. Some equipment details may, however, vary from unit to unit. A typical process flow diagram for the full-scale thermal treatment system is shown on Figure 3-1.

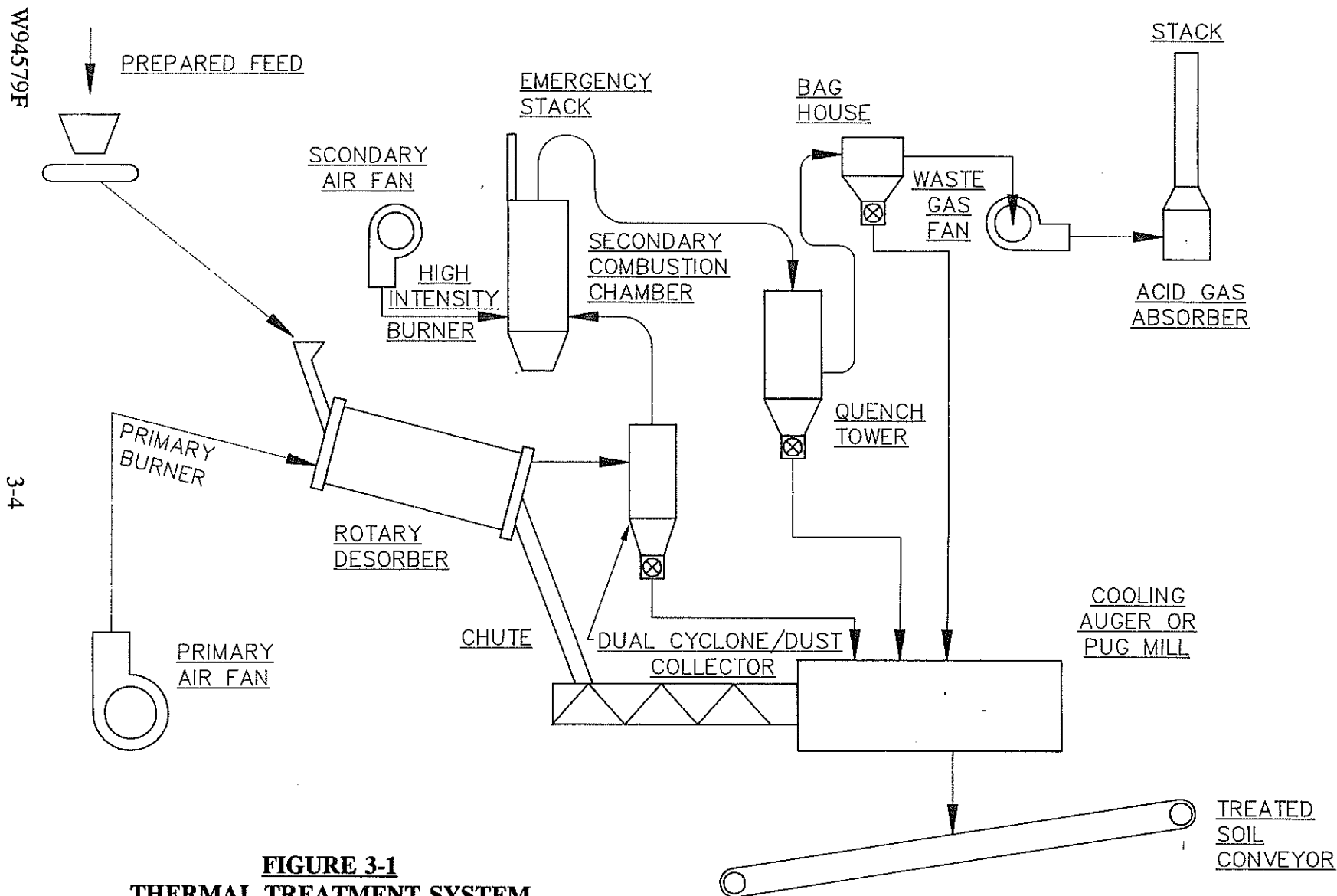


FIGURE 3-1
THERMAL TREATMENT SYSTEM
PROCESS FLOW DIAGRAM
RAYMARK INDUSTRIES SITE
STRATFORD, CONNECTICUT

The pre-screened and blended soil-waste materials are delivered to a system feed hopper by a front-end loader. The soil-waste materials is then fed out of the hopper by a horizontal variable-speed belt that controls the feed rate and delivers it to an inclined belt conveyor that transfers it to the feed chute of the primary desorber unit. The inclined belt features a weighing cell that measures the instantaneous and totalized weight of the soil-waste materials being fed to the thermal treatment system.

From the feed chute, the soil-waste materials drop into a rotating, direct-fired, co-current desorber unit. The inside of the rotary drum of the desorber unit is lined with flights that lift and drop the soil-waste materials into the hot air stream of a primary burner and air blower. These flights break up the soil-waste materials and maximize the surface area exposed to heat for effective volatilization of moisture and organic constituents. The hot treated soil-waste materials exit the end of the desorber unit and are cooled by water spray in an ash-cooling auger or are mixed with water in a pug mill.

The hot gases from the desorber unit are transferred, via steel ductwork, to dual cyclone separators operating in parallel, which remove the majority of the solids particulate from the gas stream. The solids particulates removed in the cyclone separators are transferred to the ash-cooling auger by a screw conveyor.

The exhaust gases from the cyclone separators are transferred, via steel ductwork, to a secondary combustion chamber (SCC). The SCC is a refractory-lined chamber equipped with a secondary burner and air fan to raise the gas stream temperature to about 1,800 degrees F for the destruction of organic constituents.

The hot gases from the SCC are discharged, via insulated steel ductwork, to a quench tower where water sprays reduce the gas temperature to about 400 degrees F before the gases enter a baghouse to remove residual solids particulates. An induced draft fan pulls the gas stream out of the baghouse and transfers it to an acid-gas absorber where a caustic soda solution is used to remove hydrochloric acid (HCl) and sulfur dioxide (SO₂).

The entire full-scale thermal treatment system is modular in design and is mounted on truck frames for transport and set-up at multiple sites.

3.3 Cost Estimates

As part of the treatability study subcontract, Kiber with input from Four Nines, developed a cost estimate for a 40 tons per hour conceptual, full-scale thermal treatment system, as described in Section 3.2 and as shown on Figure 3-1. Cost estimates were developed by Kiber for treating 300,000 cubic yards of soil-waste materials. A sensitivity analysis of three different soil-waste treatment volumes was prepared by HNUS.

Subcontractor's Cost Estimate

The budget-type capital expenditure for a 40 tons per hour thermal treatment system has been estimated at approximately \$300,000. The operating and maintenance costs, as described in Section 3.2 and as shown on Figure 3-1, have been estimated at about \$93.96 per ton of soil-waste materials treated, including the capital amortization cost by the Subcontractor. The total cost to treat the 300,000 cubic yards (450,000 tons) of soil-waste materials at the Raymark Industries Site was estimated at approximately \$42,281,000 by Four Nines, Inc.

This cost has been estimated on a "chute-to-chute" basis for the thermal treatment system itself only and does not include the cost of excavating, transporting, staging, blending, and pre-screening the untreated soil-waste materials or the cost of staging, transporting, and further treating and/or disposing of the treated soil-waste materials.

A detailed break-down of operating and maintenance costs is provided in the Kiber Report, which is included as Appendix B.

HNUS Cost Estimate

At the request of the EPA, a limited sensitivity analysis of costs was prepared based on three possible soil-waste volume treatment scenarios. Using design and cost factors prepared by Four Nines, Inc., and augmented by additional cost factors and refinement of Four Nines's factors, the total and unit costs for the three volumes were developed. Appendix C to this report presents the details of the cost estimates. The summary of total and unit costs are presented below, using a fee & profit factor of 30 percent applied to the direct and fixed costs, and assuming salvage value remaining for the 50,000 cubic yard scenario.

Summary of Cost Estimate Sensitivity Analysis (30% fee rate factor, salvage remaining)			
Volume (cubic yards)	300,000	150,000	50,000
Volume (tons)	450,000	225,000	75,000
Total Estimated Cost	\$43,697,000	\$26,341,000	\$12,640,000
Unit cost (\$/CY)	\$145.66	\$175.60	\$252.81
Unit cost (\$/ton)	\$97.10	\$117.07	\$168.54

After examination of the results, HNUS determined that the 30 percent fee and profit rate used by the subcontractor appeared high, and that no capital equipment salvage value for the 50,000 cubic yard scenario may exist. A second cost sensitivity analysis was prepared using a fee & profit factor of 15 percent, and assuming no salvage value remaining for the 50,000 cubic yard scenario. The lower fee rate would be more realistic for design and construction projects. Once

the asphalt batching equipment has been purchased and modified for thermal treatment use, no realizable salvage value may remain.

The second summary of total and unit costs are presented below.

Summary of Cost Estimate Sensitivity Analysis (15 % fee rate factor, no salvage remaining)			
Volume (cubic yards)	300,000	150,000	50,000
Volume (tons)	450,000	225,000	75,000
Total Estimated Cost	\$38,786,000	\$23,433,000	\$13,197,000
Unit cost (\$/CY)	\$129.29	\$156.22	\$263.93
Unit cost (\$/ton)	\$86.19	\$104.14	\$175.96

3.4 Off-gas Treatment Systems Evaluation

After completing the laboratory tests, HNUS' subcontractor developed a conceptual design of a thermal treatment system with a thermal oxidizer for off-gas control of organic vapors. At the request of EPA, HNUS also evaluated other available vapor treatment options. Brief summaries of thermal/catalytic oxidizers, condensers, and activated carbon are presented below. Should the treatability data be used to formulate of feasibility study alternatives, then selection of off-gas treatment will be dependent on organic compounds to be treated and regulatory requirements (eg. ARARs).

3.4.1 Thermal Oxidation

In this off-gas treatment process, vapor phase organic compounds are oxidized (converted to carbon dioxide and water) through combustion at temperatures of 1200 to 1800 degrees F. The process is dependent on maximizing contact between the contaminant and the high temperature combustion flame to ensure complete VOC oxidation.

VOC concentrations in the vapor stream do not provide sufficient energy to sustain the combustion process. Supplemental fuel, such as natural gas or distillate oil, is required to fully fuel the oxidation unit. Because the process requires a high operating temperature, the fuel rate and resulting total fuel cost are generally quite high.

Thermal oxidation is effective for nearly complete destruction of most VOCs. Destruction efficiencies in excess of 95 percent are commonly achieved by this process. For inlet vapor streams with concentrations in excess of 100 ppm, destruction efficiencies of greater than 99

percent are typically achieved. For vapor streams containing high concentrations of halogenated VOCs, a downstream scrubber is usually required to minimize the release of halogenated acid gases.

Thermal oxidation is applicable for destruction of the vapor phase contaminants that would be generated from the thermal treatment of soil-waste materials.

3.4.2 Catalytic Oxidation

In this process, vapor phase VOCs are oxidized with the help of a catalyst. The process is similar to thermal oxidation in that heat is used to oxidize VOCs; however, because the catalyst lowers the oxidation activation energy of the VOCs, combustion occurs at much lower temperatures (300 to 800 degrees F). The catalyst is an active material such as platinum, palladium, or a metal oxide on an inert ceramic or metal substrate. The vapor stream is heated by indirect contact with exhaust gases, then passed through the catalyst bed where oxidation is initiated.

Catalytic oxidation is effective for nearly complete destruction of most VOCs. Destruction efficiencies in excess of 95 percent are achieved by this process. Catalytic oxidation is typically ineffective in handling halogenated compounds and metals that deactivate the catalyst. Specialized catalysts that are resistant to halogens are available. A downstream scrubber is required to minimize the potential release of halogenated acid gases.

The primary advantages of catalytic oxidation over thermal oxidation are the lower operating temperature (therefore lower fuel requirements and operating costs), and lower emissions of carbon dioxide and nitrogen oxides that result from using less fuel.

Because of the presence of halogens, catalytic oxidation may have limited application for destruction of the vapor phase organic contaminants generated by the thermal treatment of soil-waste materials.

3.4.3 Condensation

Condensers are used to recover vapor phase organic compounds by lowering the temperature of an emission stream, causing the vapor to reach saturated condition and condense into the liquid phase. Coolants are used in the condenser to reduce the temperature of the waste stream. The inlet organic vapor concentration can only be lowered to the saturation concentration (or vapor pressure) of the temperature of the coolant. Therefore, if air or water (ambient temperatures) is used as the condenser coolant, a high inlet organic vapor concentration (especially VOCs) would not be effectively reduced through condensation and would result in a high outlet vapor concentration. Chilled water or refrigerant would be required as a condenser coolant to achieve lower vapor stream temperatures so that more VOCs are condensed.

Mr. Paul DePercin of RREL in Cincinnati, Ohio, was contacted to obtain information on the use of condensers off-gas treatment in thermal treatment studies under the EPA's SITE program. Mr. DePercin stated that currently, three LTTD studies were addressing PCB-contaminated soils. All LTTD units were equipped with condensers and activated carbon adsorption units to capture uncondensed organics. However, highly volatile VOCs such as vinyl chloride and methylene chloride would not be easily captured by the condensers or activated carbon. Usually, discussion with the state will be required to address allowable total VOC emissions from the stack. Mr. DePercin also indicated that the LTTD units in the SITE program were all indirect-heated units where a heated fluid is circulated around the jacket of the units. Much less air flow (i.e. more saturated vapor) is forced through these units in comparison with direct-fired thermal treatment units. The condensers on the SITE LTTD units would be much smaller and more efficient than the direct-fired thermal treatment units, which would have much higher air flow rates (i.e. less saturated vapor).

A condenser vendor, Graham Manufacturing of Batavia, New York, was contacted to obtain information on the viability of condensing various organic vapors that could be generated by a thermal treatment unit. Graham Manufacturing was provided with analytical data developed under the thermal treatment treatability study; physical and chemical properties of representative PCBs, SVOCs, and VOCs (molecular weights, vapor pressure); and estimated process rates (throughput, organics mass loading, and temperatures; as presented in Appendix B of the Kiber report). One goal was to reduce the process air temperature leaving the thermal treatment unit (900 degrees F) to ambient conditions (70 degrees F). Based on a limited assessment of the data provided, Mr. Don Ruck of Graham Manufacturing indicated that roughly 90 percent of the PCBs would be condensed. None of the SVOCs or VOCs were likely to be condensed because their vapor pressures would be too high for condensation to work effectively. A condenser operating at much lower temperatures would probably be required to remove some of the SVOCs and VOCs. However, problems with water vapor freezing will be encountered since the organic vapor mass is only a small percentage of the vapor stream; freezing of moisture could clog the condenser system. Mr. Ruck estimated a water- or refrigerant-cooled coil-type condenser constructed of stainless steel, approximately 48 inches diameter by 20 feet long, would cost about \$200,000. It is anticipated that moisture-laden air cooled from 900 degrees F to 70 degrees F would require significant amounts of energy and would therefore be costly.

Use of condensers to capture vapor phase contaminants generated from the thermal treatment of soil-waste materials may not be efficient if low saturated vapor conditions and high initial temperatures are encountered.

3.4.4 Activated Carbon Adsorption

In this process, organic and some inorganic compounds are captured on the surface of activated carbon (carbon treated to produce a large surface to volume ratio, thus exposing a maximum number of carbon atoms to act as adsorbers), which is the most common adsorbent used for organics removal.

In general, compounds with high molecular weight, polarity, and the degree of cyclization (i.e., ringed compounds) are more easily adsorbed than are straight-chained compounds). Adsorption is also affected by temperature and pressure. Adsorptive capacity decreases with increasing temperature; the operating temperature should be less than 100 degrees F for maximum effectiveness.

Carbon adsorption is rapid and essentially removes all organics in a waste stream. Eventually the carbon becomes saturated with contaminants and the efficiency drops and breakthrough (of contaminants) occurs. Depending on the inlet concentration of contaminants and the design of the carbon bed (amount of carbon, bed depth), the adsorption process can operate from as little as two hours to several days before breakthrough occurs.

The primary limitation of using carbon adsorption to remove organics is economic and is highly dependent on the concentration of contaminants in the inlet waste stream. Highly contaminated waste streams result in carbon becoming spent very quickly. The process becomes expensive because of carbon disposal costs or the added "down-time" and costs associated with frequent regeneration of the carbon beds.

The off-gases from the thermal treatment of site soil-waste materials will require cooling to lower temperatures prior to activated carbon adsorption. Activated carbon would not be effective if low-molecular, non-polar compounds have to be removed from the emissions. Activated carbon may be more suitable as a secondary or polishing treatment step.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The following conclusions can be drawn from the bench-scale thermal treatment treatability study:

- The primary objective of the treatability study has been met. Results of the study show that the PCBs content of soil-waste materials samples representative of conditions at the Raymark Industries Site can be successfully removed down to less than 2.0 mg/kg by using thermal treatment.
- The treatability study results show that a minimum operating temperature of 900 degrees F must be used to achieve the primary objective.
- The treatability study results show that the minimum detention time to achieve the primary objective is 60 minutes. However, this figure was obtained with a stationary, indirect-fired laboratory muffle furnace and, therefore, does not reflect the heat transfer efficiency achievable with a direct-fired rotary thermal treatment unit. Accordingly and based on actual experience for similar applications, a conservative design detention time of 15 minutes has been selected.
- The preferred type of full-scale thermal treatment system is a direct-fired desorber-incinerator unit. Reasons for that selection include the ready availability of thermal treatment systems of that type with adequate processing capacity (40 tons/hour), the higher heat transfer efficiency resulting in a lower allowable detention time, and the lower capital and operation and maintenance costs.
- The treatability study results show that the thermal treatment process essentially removes all SVOCs from the soil-waste materials.
- However, the effect of thermal treatment on TOC has proved quite variable from sample to sample with complete or near-complete removal for samples TS*B-10*1.5-4 and TS*B-68*2-4, but no significant removal for either samples TS*B-68*6-8 or TS*B-7*4-6. The TOC values for as-received and treated samples may be affected by the moisture content of the samples.
- The 2 percent by weight organic concentration limit allowable in the feedstock of a thermal treatment system may be exceeded on a number of occasions, as all but one (TS*B-10*1.5-4) of the four as-received samples showed TOC values in excess of 20,000 mg/kg. However, TOC analytical data has proven somewhat erratic and the results obtained for the as-received samples may not be representative of the conditions of the majority of the contaminated soil-waste materials at the Raymark Industries Site. It is also possible to raise the allowable

feedstock organic concentration to 4 percent with upgraded controls; it is probable that the organic concentration of the feedstock may be controlled through selective excavation and handling of organic hot-spots and judicious blending of the soil-waste materials from various areas.

- The results of the treatability study show that the thermal treatment process has no significant impact on the metals content of the soil-waste materials.
- The estimated budget-type capital cost of a 40 ton/hour on-site mobile thermal treatment system is approximately \$3,000,000. The estimated operating and maintenance costs for such a system is approximately \$95 per ton of soil-waste materials treated. The "chute-to-chute" total cost for the thermal treatment of the 450,000 tons of soil-waste materials at the Raymark Industries Site is estimated at approximately \$42,750,000.
- Based on discussions with RREL and a condenser manufacturer, HNUS concludes that condensers may not be efficient or cost-effective substitutes for thermal or catalytic oxidizers as off-gas treatment units since vinyl chloride and methylene chloride are present in site soils. Condensation is likely to be ineffective in removing significant quantities of these VOCs and other VOCs with high vapor pressures, from an unsaturated air emission stream.
- Activated carbon may also be inefficient or highly costly to use as a primary treatment step, in capturing VOCs with low molecular weights, and non-polar compounds (vinyl chloride, methylene chloride, ketones, and alcohols). However, activated carbon can be used as a secondary treatment step if the problematic VOCs are first removed from the emission stream.
- Actual selection and design of the off-gas treatment system for a thermal treatment system will be dependent on the types of organic compounds to be treated and the allowable state air emission limit. Both vinyl chloride and methylene chloride are considered hazardous air pollutants under Connecticut General Statutes.

4.2 Recommendations

The following recommendations are made as a result of this bench-scale thermal treatment treatability study:

- The Feasibility Study for the Raymark Industries Site should proceed on the assumption that it is possible to remove PCBs from the soil-waste materials to less than 2.0 mg/kg by using a thermal treatment system.

- The thermal treatment system selected for this application should be of the direct-fired desorber-incinerator type with an operating capacity of 40 tons per hour. This thermal treatment system should be designed to accept soil-waste materials particle sizes of up to 2 inches and should feature a rotary type desorber unit equipped with internal devices to maximize heat transfer efficiency and minimize detention time requirements.
- Additional site characterization or a more thorough review of the existing data must be performed to determine a representative average total organic concentration for the soil-waste materials and establish if this concentration will exceed the 2 to 4 percent by weight allowable in an thermal treatment system feedstock. As required, an evaluation may also have to be performed to determine the feasibility of segregating organic hot-spots for alternate treatment.
- Once the representative nature of certain soil-waste materials samples has been verified, these samples should be tested for specific parameters to help refine the design of the thermal treatment system. These parameters include: higher heating value, ultimate and proximate analysis, ash content, total petroleum hydrocarbons, and organic sulfur and chlorine content.
- Bench- or pilot-scale tests should be performed to determine the most effective means of conveying and feeding the soil-waste materials to, within, and from the thermal treatment system. This is particularly important for the moister, more cohesive material such as that in samples TS*B-68*6-8 and TS*B-7*4-6.

APPENDIX A

WORK PLAN FOR BENCH-SCALE LOW TEMPERATURE THERMAL DESORPTION TREATABILITY STUDY

WORK PLAN

BENCH-SCALE LOW TEMPERATURE THERMAL DESORPTION TREATABILITY STUDY

RAYMARK INDUSTRIES SITE
STRATFORD, CONNECTICUT

WORK ASSIGNMENT No. 42-1LH3
HALLIBURTON NUS PROJECT 0890

MARCH 1994

WORK PLAN
BENCH-SCALE LOW TEMPERATURE THERMAL DESORPTION TREATABILITY STUDY
RAYMARK INDUSTRIES SITE - STRATFORD, CONNECTICUT

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WORK PLAN
BENCH-SCALE LOW TEMPERATURE THERMAL DESORPTION TREATABILITY STUDY
RAYMARK INDUSTRIES SITE - STRATFORD, CONNECTICUT

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1.0 GENERAL DESCRIPTION

1.1 Project Description

Halliburton NUS Corporation is performing an Engineering Evaluation/Cost Analysis (EE/CA) on behalf of the U. S. Environmental Protection Agency (EPA) for the Raymark Industries Site.

As part of this EE/CA, a bench-scale Low Temperature Thermal Desorption (LTTD) treatability study will be performed to evaluate the effectiveness of LTTD in reducing the PCBs concentration of contaminated soil-waste materials to less than 2.0 mg/kg.

This treatability study is being performed on a very tight schedule and all efforts shall be made to expedite the overall progress of the study.

1.2 Project Background

The Raymark Industries Site located in Stratford, Connecticut was a manufacturer of friction materials containing asbestos and non-asbestos materials, inorganics, phenol-formaldehyde resins, and various adhesives. Primary products were gasket material, sheet packing and friction materials including clutch facings, transmission plates, and brake linings. As a result of these activities, soils at the site have been primarily contaminated with asbestos, lead, and PCBs.

The current and very preliminary estimate of the volume of contaminated soil-waste materials is about 300,000 cubic yards. For the purpose of this specification, the term soil-waste material means soils mixed with various manufacturing wastes including asbestos and other contaminated materials. There are at least fifteen currently identified satellite areas, each area consisting of a large number of properties, where Raymark waste is known to have been received and used as fill around the Town of Stratford. These sites consist of commercial, residential and municipal properties. These sites are considered part of the "site", a number of properties within the satellite areas have been designated a health hazard and are the focus of time-critical removal actions. The excavated waste from these properties is currently being stored, on a temporary basis, at the Raymark facility until a final cleanup option is selected. Based on the sampling results for soil-waste materials obtained from the Raymark Industries facility, maximum concentrations of contaminants detected are presented in Table 1-1.

TABLE 1-1

MAXIMUM CONCENTRATIONS DETECTED AT THE RAYMARK INDUSTRIES PROPERTY
STRATFORD, CONNECTICUT

Analyses	Constituent	Maximum Concentration ($\mu\text{g/kg}$)	Detection Limit ($\mu\text{g/kg}$)	Depth (feet)
VOA (EPA Method 8240)	Acetone	3,893	100	8 to 10
	Benzene	80.4	5	8 to 10
	2-Butanone	28,046	100	8 to 9
	Carbon Disulfide	209	100	7 to 8
	Chlorobenzene	141,379	5	8 to 9
	1,2-Dichlorobenzene	195	5	8 to 9
	1,4-Dichlorobenzene	138.0	5	8 to 9
	1,1-Dichloroethane	2,287	5	8 to 9
	1,2-Dichloroethane	35	5	8 to 9
	1,1-Dichloroethene	148.6	5	15 to 17
	trans-1,2-Dichloroethene	202	5	8 to 10
	Ethylbenzene	22,644	5	8 to 9
	2-Hexanone	109.6	50	8 to 10
	4-Methyl-2-Pentanone	1,399	50	4 to 6
	Styrene	367	5	0 to 2
	Tetrachloroethene	20.2	5	45 to 47
	Toluene	2,569,620	5	4 to 6
	1,1,1-Trichloroethane	116.7	5	20 to 22
	1,1,2-Trichloroethane	544	5	48 to 50
	Trichloroethane	2,196	5	41 to 43
	Vinyl Chloride	514	10	8 to 10
	Xylenes	113,908	5	8 to 9

TABLE 1-1
 MAXIMUM CONCENTRATIONS DETECTED AT THE RAYMARK INDUSTRIES PROPERTY
 STRATFORD, CONNECTICUT
 PAGE TWO OF FOUR

Analyses	Constituent	Maximum Concentration (mg/kg)	Detection Limit (mg/kg)	Depth (feet)
SVOC (BNA) (EPA Method 8270)	Acenaphthene	12.6	4.4	0 to 8
	Acenaphthylene	10.4	4.4	0 to 8
	Anthracene	36.5	4.4	0 to 8
	Benzo (a) anthracene	61.7	4.4	0 to 8
	Benzo (b) fluoranthene	35.1	4.4	0 to 8
	Benzo (k) fluoranthene	47.6	4.4	0 to 8
	Benzo (g,h,i) perylene	10.8	4.4	0 to 8
	Benzo (a) pyrene	26.1	4.4	0 to 8
	Bis (2-ethylhexyl) phthalate	27.4	3.6	0 to 10
	Butyl benzyl phthalate	16.9	3.6	0 to 10
	Chrysene	54.0	4.4	0 to 8
	Dibenzofuran	11.1	4.4	0 to 8
	Di-n-butylphthalate	36.6	5.4	6 to 11
	2,4-Dimethylphenol	19.3	1.2	2 to 12
	Fluoranthene	170.4	4.4	0 to 8
	Fluorene	32.4	4.4	0 to 8
	Indeno (1,2,3-cd) pyrene	9.4	4.4	0 to 8
	Isophorone	33.6	3.8	92 to 102
	2-Methylnaphthalene	6.2	4.4	0 to 8
	2-Methylphenol (o-cresol)	3.2	1.2	2 to 12
	3-Methylphenol (m-cresol)	55.9	1.2	2 to 12
	4-Nitrophenol	0.5	0.4	34 to 38
	Napthalene	5.3	4.4	0 to 8
	Phenanthrene	154.3	4.4	0 to 8
	Pyrene	139.6	4.4	0 to 8

TABLE 1-1

MAXIMUM CONCENTRATIONS DETECTED AT THE RAYMARK INDUSTRIES PROPERTY
 STRATFORD, CONNECTICUT
 PAGE THREE OF FOUR

Analyses	Constituent	Maximum Concentration ($\mu\text{g/kg}$)	Detection Limit ($\mu\text{g/kg}$)	Depth (feet)
Chlorinated Herbicides (EPA Method 8150)	2,4-Dichlorophenylacetic Acid	398	NR	2 to 12
	2,4-D	670	NR	6 to 11
	Dinoseb	100	NR	2 to 12
	2,4,5-T	1,020	NR	8 to 11
	2,4,5-TP (Silvex)	1,700	NR	38 to 48
Organophosphorus Pesticides (EPA Method 8140)	Triphenylphosphate	203	NR	0 to 8
	Diallate	540	NR	0 to 8
	Dimethoate	125	NR	38 to 44
	Disulfoton	1,000	NR	0 to 8
	Famphur	180	NR	0 to 8
	Methyl Parathion	680	NR	0 to 10
	Parathion	125	NR	38 to 44
	Phorate	340	NR	2 to 12
	Pronamide	780	NR	7 to 15
	Sulfotep	125	NR	38 to 44
	Thiazin	118	NR	52 to 62
Sulfide (EPA Method 9030)	Sulfide	250 mg/kg	37 mg/kg	12 to 22
Cyanide (EPA Method 9012)	Cyanide	8.3 mg/kg	NR	0 to 8
Metals (EPA Methods)	Antimony	30,182	1,000	6 to 11
	Arsenic	130,208	200	0 to 8
	Barium	2,314,400	400	7 to 15
	Beryllium	8,400	500	0 to 4

TABLE 1-1
 MAXIMUM CONCENTRATIONS DETECTED AT RAYMARK INDUSTRIES PROPERTY
 STRATFORD, CONNECTICUT
 PAGE FOUR OF FOUR

Analyses	Constituent	Maximum Concentration (µg/kg)	Detection Limit (µg/kg)	Depth (feet)
Metals (EPA Methods)	Cadmium	10,364	500	6 to 11
	Chromium	316,949	1,000	0 to 10
	Cobalt	87,100	5,000	0 to 4
	Copper	67,966,101	NR	0 to 10
	Lead	57,230,769	NR	2 to 11.5
	Mercury	1,017	100	0 to 10
	Nickel	774,576	4,000	0 to 10
	Selenium	67,470	NR	0.5 to 2
	Silver	6,780	1,000	0 to 10
	Thallium	781	500	10 to 18
	Tin	229,730	4,000	0 to 8
	Vanadium	103,000	NR	0 to 4
	Zinc	13,175,675	NR	0 to 8
PCBs (Method NR)	Aroclor 1268	190 mg/kg ^a	0.1 mg/kg	0 to 10
Dioxin (EPA Method 8280)	Dioxin TEF	7.2162	N/A	0 to 10
Asbestos (EPA Method NR)	Chrysotile	40-45%	N/A	0 to 10
	Cellulose	30-35%	N/A	15 to 18.5
	Matrix	99-100%	N/A	10 to 15
	Synthetic	1-2%	N/A	12 to 22

NOTES:

^a Approximate Value.

N/A = Not Applicable.

ND = Not Detected.

NR = Not Recorded.

TEF = Toxicity Equivalence Factor.

Note: Extracted from Final Site Inspection Report prepared by Roy F. Weston, Inc. dated September 30, 1993.

1.3 Request For Proposals and Subcontractor Selection

Halliburton NUS solicited proposals to conduct a bench-scale soil solidification and stabilization treatability study at the Raymark site.

Halliburton NUS prepared a Request For Proposal (RFP) and sent it to seven (7) qualified potential subcontractors including CleanSoils, Inc., Halliburton Services, Kiber Environmental Services, Rust Remedial Services, Testco Tank & Pump, Inc., VFL Technology, and Weston Services Inc. In response to this RFP, proposals were received from two of the seven potential subcontractors, including Kiber Environmental Services, and Rust Remedial Services.

The proposals received were evaluated independently by three senior Halliburton NUS engineers and graded in accordance to the criteria presented in the RFP, including bidder's qualifications, technical merit and adequacy of the proposed testing technology, and treatability study design. As a result of this evaluation, Rust Remedial Services was initially selected as the more qualified firm performance of the LTTD treatability study. However, Rust Remedial Services' price proposal proved to be unacceptable even after negotiation and the subcontract was awarded instead to Kiber Environmental Services (Kiber).

This work plan was prepared by revising the Technical Specifications included in the RFP to incorporate pertinent information provided by Kiber in their technical proposal.

2.0

TREATABILITY STUDY OBJECTIVES

The primary objective of this treatability study is to determine the feasibility of using LTTD in reducing the PCBs concentration of contaminated soil-waste materials to less than 2.0 mg/l.

The secondary objective of this treatability study is to evaluate the effect of the LTTD process on the other organic compounds, asbestos, and metals content of the contaminated soil-waste material.

3.0

TECHNOLOGY DESCRIPTION

Low temperature thermal desorption, in simplest terms, is an ex-situ process that uses either direct or indirect heat exchange to vaporize organic contaminants from soil or sludge. Air, combustion gas or inert gas can be used as the transfer medium for the vaporized components. LTDD systems are physical separation processes and are not specifically designed to destroy organic contaminants.

The factors that can influence the ability of a LTDD process includes the level and type of contaminant and the soil type. The performance of a LTDD system is measured by the reduction in contaminant levels.

The temperature with which LTDD processes are used is generally from 500 to 1,300 °F. While temperature is an important process consideration, another parameter is retention time, or the time with which the average medium temperature is at or above the target temperature. Soil type, thermal properties of contaminants, contaminant levels and moisture content will also affect LTDD processes.

LTDD is most applicable to organic contaminants. Once in the gaseous state, the contaminants can be treated further by a higher temperature thermal treatment process which will essentially destroy the contaminants or by adsorbing the contaminants onto carbon. Other means of treating off gases include thermal oxidation and chemical neutralization.

By controlling the temperatures within the treatment unit, groups of contaminants can be selectively removed. Vapor pressure of specific contaminants will vary as a function of temperature for specific contaminants.

Full-scale LTDD treatment requires excavation and transportation of the contaminated materials to the treatment unit. Generally, LTDD treatment systems will have some type of screening/pretreatment prior to being transferred to the desorption unit. Belt conveyors are used in transfer soils from the screening equipment to the LTDD system. Contaminated screened materials can be crushed in a power screen or similar pulverizing device and either placed into the LTDD unit or treated using an alternate treatment method. A general LTDD flow sheet can be found as Figure 1. This figure represents the basic equipment that would be used in this type of full-scale treatment process.

Since organics are often the contaminant that is being treated by LTDD, some type of containment to limit the volatiles emitted during excavation, hauling and treatment is generally required. Some sites actually require enclosures to contain the volatiles that are emitted.

While there are many variations in the LTTD equipment, they all share a requirement of having to treat off gases generated from the treatment process. One such method of treating off gases is through the use of a scrubber system. Particulate can be removed using dust filters while off gases must be adhered to carbon or transferred to a liquid state by condensing onto a wet scrubber. Once in a liquid state the contaminants can be removed or destroyed by a variety of physical/chemical treatment processes.

4.0 **EXPERIMENTAL DESIGN AND PROCEDURES**

4.1 **Treatability Study Approach**

At the start of the treatability study, Halliburton NUS will collect representative soil-waste material samples and ship them to Kiber's testing facility in Atlanta, Georgia.

Upon receipt of the soil-waste material samples, Kiber will blend them and perform an initial characterization by measuring the analytical parameters as shown on Table 6-1.

The LTTD testing will then be performed in two phases, including Intermediate Testing and Final Testing.

During Intermediate Testing, Kiber will perform various tests at different temperatures and residence times to determine what temperature and residence time will achieve the stated objectives of treatment.

During Final Testing, Kiber will confirm the results from the initial tests and perform more extensive analytical and physical properties testing on the treated materials.

4.2 **Sample Collection**

Halliburton NUS will collect four (4) 5-gallon soil-waste material samples. Halliburton NUS will also ship these samples to Kiber's testing facility in DOT-approved, metal containers.

Approximate anticipated sample contaminant concentrations are shown on Table 4-1.

Procedures for the collection and shipment of the soil-waste material sample at the Raymark Industries Site by Halliburton NUS will be described in an addendum to the Health and Safety Plan prepared by Halliburton NUS for the Stratford, Connecticut Technical Assistance work assignment.

4.3 **Initial Sample Characterization**

The samples received by Kiber will be logged into a tracking system. All samples are to be appropriately marked and stored as required for contaminated soil samples. Samples will be processed by combining all material for each sample into a mixing container and hand mixing the material with a trowel until it has a uniform homogenous appearance. Upon completion of homogenization, representative specimens of each sample will be measured for the physical and chemical parameters listed in the "As-Received" analytical requirements shown on Table 6-1.

All analytical work, except for asbestos and PCBs measurements will be performed at Kiber's testing facility. Specimens for asbestos and PCBs analysis will be placed by Kiber in clean, sealable containers and transported to the appropriate analytical lower-tier subcontractors the same day.

The remainder of each sample will be stored by Kiber in sealed buckets at cool temperature (4°C) until required for subsequent testing.

The results for the initial characterization will be reviewed by Kiber and Halliburton NUS immediately upon completion to determine that the samples are representative of materials to be treated at the Raymark Industries Site as shown on Table 4-1.

4.4 Low Temperature Thermal Desorption Testing

4.4.1 Intermediate Testing

The intermediate LTDD treatability testing will be performed to determine if PCBs can be thermally destroyed using this technology and determine the effects of the treatment process on the concentrations of asbestos, and metals. Kiber will perform various tests at different temperatures and residence times to determine what temperature and residence time will achieve the stated objectives of treatment. Nine (9) intermediate test runs will be performed for each of the four samples for a total of thirty-six (36) test runs.

The intermediate LTDD tests will be conducted using a muffle furnace. A metal (stainless steel or inconel) tray will be cleaned, dried and weighed. Approximately 1 kilogram (Kg) (2.2 pounds) of soil-waste material, will be placed on the tray in a shallow layer. The tray will be weighed and the mass of soil-waste material used for the test run recorded. The tray will then be placed in the pre-heated muffle furnace and kept at a steady pre-set temperature for a selected length of time. The Intermediate Testing matrix for each soil-waste material sample may be summarized as follows:

Temperature (°F)	700			1,000			1,200		
Residence Time (min)	10	20	40	10	20	40	10	20	40
Test Run No.	1	2	3	4	5	6	7	8	9

A thermocouple will be used to monitor the temperature of the soil-waste material sample being treated. The treated sample will be cooled to room temperature in air after the tray is removed from the furnace. The tray will be then weighed and the mass of the weight of the treated sample will be recorded.

TABLE 4-1

APPROXIMATE TEST SAMPLES CHARACTERIZATION
LOW TEMPERATURE THERMAL DESORPTION TREATABILITY STUDY
RAYMARK INDUSTRIES - STRATFORD, CONNECTICUT

Sample Description	Asbestos Content (%)	Total PCBs (mg/kg)	Lead (mg/kg)
On-site 1	5 - 85	2 - 10	500 - >10000
On-site 2	5 - 85	50 - 75	500 - >10000
On-site 3	5 - 85	200 - 300	500 - >10000
Off-site 1	5 - 85	2 - 10	500 - >10000
Off-site 2	5 - 85	50 - 75	500 - >10000
Off-site 3	5 - 85	200 - 300	500 - >10000
Off-site 4	< 25	< 50	100 - < 10000

Notes: 1) Total PCBs include Aroclors 1262 and 1268

2) Sample characteristics based on EPA TAT field screening data (April 1993)

The treated soil-waste material samples for each Intermediate Testing run will be tested for the chemical parameters as listed in the "Intermediate Testing" analytical requirements shown on Table 6-1.

The Intermediate Testing results will be reviewed by Kiber and Halliburton NUS and an optimum operating temperature and residence time will be selected for each soil-waste material sample. In their evaluation of the Intermediate Testing Results, Kiber will be assisted by a lower-tier thermal treatment subcontractor.

4.4.2 Final Testing

The purpose of the Final Testing will be to confirm the results from the Intermediate Testing of each soil-waste material sample at the selected operating temperature and residence time and to perform more extensive physical and chemical analytical testing on the treated samples.

Kiber will use the same procedures as for the Intermediate Testing to perform the Final Testing.

Kiber will test each treated sample from the Final Testing for the physical and chemical parameters as listed in the "Final Testing" analytical requirements shown on Table 6-1.

4.5 Full-Scale System Conceptual Design and Cost Estimate

Kiber and Halliburton NUS will prepare a Conceptual Design to identify the equipment and operating requirements for a full-scale LTTD system. Based on this Conceptual Design, Kiber and Halliburton NUS will develop realistic budget-type (± 25 percent accuracy) capital expenditure and operating and maintenance cost estimates on a per-ton basis.

The Conceptual Design will include a Process Flow Diagram (PFD) for a full-scale LTTD system. This PFD will identify the main items of process equipment and defining the flow and anticipated composition of the main process streams. The PFD will also include a preliminary heat balance for the LTTD system.

The Conceptual Design will identify and size each major piece of process and control equipment required for a full-scale LTTD system based on the results of this and other similar treatability studies performed by Kiber, their lower-tier thermal treatment subcontractor, and Halliburton NUS, and on the available information regarding site-specific conditions. The operating and maintenance costs estimate will include a discussion of the site conditions that may affect treatment rates, of the options that may optimize the treatment system, and of the conditions which may hamper operation of the treatment system.

The conceptual design will begin early in the treatability study and run parallel with the LTDD testing. In the preparation of the conceptual design and budget-type cost estimates, Kiber will be assisted by their lower-tier thermal treatment subcontractor with experience on projects involving similar waste materials.

5.0 EQUIPMENT AND MATERIALS

Kiber will supply, all equipment, materials, and reagents necessary for the bench-scale LTDD treatability study.

The main piece of equipment used for the bench-scale testing will be a muffle furnace. The muffle furnace which Kiber will use is a Fisher Scientific 750 Series Model No. 58. The temperature of this muffle furnace is controlled electronically and can be set as high as 1,100 °C (2,012 °F).

6.0 TREATABILITY SAMPLING AND ANALYSIS

6.1 Analytical Schedule

Table 6-1 lists the physical and chemical analytical requirements for the LTTD treatability study.

Kiber will perform the bench-scale treatability testing in such a way that the four As-Received soil-waste material samples and the four Final Testing samples will be subjected to comprehensive physical and chemical analyses as identified on Table 6-1.

Treated samples from the Intermediate Testing runs will only be measured for a limited number of parameters as also identified in Table 6-1.

Sample collection, preservation, container materials and volumes, tracking, analytical work and Quality Assurance/Quality Control (QA/QC) measures will be conducted in accordance with EPA protocols specified in SW-846, 3rd edition and all updates.

Contract Laboratory Program (CLP) procedures or the stringent validation or documentation procedures are not required.

6.2 Quality Assurance Plan

Kiber's corporate QA/QC Plan is included in Appendix A. This plan will be adhered to for the performance of the LTTD treatability study.

Appropriate QA/QC samples will be collected during the LTTD treatability study at a rate of 10 percent or once per day, whichever is more frequent.

The laboratory QA/QC includes the analysis of duplicates, matrix spikes and matrix spike duplicates. The following QA/QC will be enforced for the Raymark treatability study:

- All data, including the QA data, will be maintained and available for reference or inspection by Halliburton NUS.
- A minimum of one blank for every 10 extractions that have been conducted in an extraction vessel will be employed as a check to determine if any memory effects from the extraction equipment are occurring.
- For each analytical batch, a matrix spike and a matrix spike duplicate will be performed. The purpose of the matrix spike analysis is to monitor the adequacy of the analytical methods and to determine if matrix interferences exist in analyte detection.

TABLE 6-1
SUMMARY OF ANALYTICAL WORK SCOPE
SOIL LOW TEMPERATURE THERMAL DESORPTION TREATABILITY STUDY
RAYMARK INDUSTRIES SITE
STRATFORD, CONNECTICUT

Sample Description	Number of Samples	Analytical Parameters	Analytical Method Reference
As Received Waste Material	4	Moisture Content Total Organic Carbon (TOC) Pesticides/PCBs ² Volatile Organic Compounds Semivolatile Organic Compounds Grain Size Dioxins	ASTM D2216 MSA 20.3.5.2 ¹ SW846-3550/8080 SW846-8240 SW846-3550/8270 ASTM D422-63 (R1972) SW846-3550/8280
Intermediate Testing (Run No. 1-9)	36	PCBs ²	SW846-8080
Final Testing (Run No. 10)	4	Moisture Content Total Organic Carbon (TOC) Pesticides/PCBs ² Volatile Organic Compounds Semivolatile Organic Compounds Dioxins	ASTM D2216 MSA 20.3.5.2 ¹ SW846-8080 SW846-8240 SW846-3550/8270 SW846-3550/8280

NOTES:

ASTM: American Society for Testing and Materials

MSA: Method of Soil Analysis

SW846: Test Methods For Evaluating Solid Wastes, Physical/Chemical Methods, SW-846, 3rd. Edition November 1986 and all updates

1. Method for Soil Analysis - Wakley-Black Procedure

2. PCBs include Aroclors 1262 and 1268

- All QC measures described in Kiber's corporate QA/QC Plan or the appropriate analytical methodologies will be implemented.
- All analyses will be conducted within analytical holding times as specified by the analytical methods shown on Table 6-1.

6.3 Analytical Reports

To facilitate decision-making throughout the treatability study and expedite the preparation of the LTDD Treatability Study Report, Kiber will report analytical data to Halliburton NUS on a weekly basis along with pertinent test information (i.e. testing conditions).

6.4 Data Evaluation

All data generated during the treatability study will be critically reviewed by Kiber, their lower-tier thermal treatment subcontractor, and Halliburton NUS for accuracy and to correlate changes in the testing parameters with the treatment process effectiveness. In the event of irregularities in the data, or anomalies, it may be necessary to repeat analyses. Data evaluation is also discussed in Section 8.0 of this Work Plan.

6.5 Data Validation

The analytical data generated by Kiber and their lower-tier analytical subcontractors may be subject to data validation. Data validation includes a careful examination of laboratory tracking procedures, QA/QC records, logbook notes and other information that relates to the reliability and quality of the data. Data validation will be conducted by Halliburton NUS, if necessary.

7.0

DATA MANAGEMENT

Kiber will summarize the procedures used for recording observations and raw data.

Kiber will keep detailed logs and records for all testing activities, including any pretreatment or post-treatment steps. Testing procedures will be well documented, using bound notebooks, photographs, etc., and back-up copies of critical data items will be made. As appendices to the LTTD Treatability Study Report, Kiber will include copies of all drawings, logs, records, data, and other documents generated during the project. Appendices will also include, but not be limited to, the following items:

- Sample Chain-of-custody form
- Sample progress record or internal laboratory tracking document
- Sample preparation logs
- Reagent preparation logs
- Treatability study logs
- Sample submission for analysis
- Raw laboratory data
- Laboratory QC summary sheets (duplicates, spikes, blanks, etc.)
- Overall QC summary of laboratory analyses
- Computation sheets
- Data reduction summary

8.0 DATA ANALYSIS AND INTERPRETATION

Kiber will analyze raw data in such a manner as to reduce this data to a form useful for interpretation by themselves, their lower-tier thermal treatment subcontractor, and Halliburton NUS.

Major differences between anticipated and actual results may necessitate modifications of the treatability study test procedures and retesting of the technology.

All results are useful and shall be reported as they can be used by Halliburton NUS as justification for design or budget modifications.

9.0

HEALTH AND SAFETY

Kiber's corporate Health and Safety Plan, which will be followed for the performance of the bench-scale LTTD treatability study is included as Appendix B.

Health and Safety requirements for the collection and shipment of the soil-waste material sample at the Raymark Industries Site by Halliburton NUS will be described in an addendum to the Health and Safety Plan prepared by Halliburton NUS for the Stratford, Connecticut Technical Assistance work assignment.

10.0 **MANAGEMENT OF TESTING RESIDUALS**

Testing residuals will include unused as-received soil-material samples, and successfully or unsuccessfully treated samples.

Kiber will store residuals for the duration of the treatability study and return them to the Raymark Industries Site at the conclusion of the study. Return of the testing residuals to the Raymark Industries Site will be coordinated through Halliburton NUS. Kiber will pack and ship testing residuals in accordance to applicable D.O.T. regulations.

During the treatability study, Kiber will store the testing residuals at their facility in accordance to all applicable Federal, State, and local requirements.

11.0 REPORTS

Kiber will prepare and submit to Halliburton NUS for review and approval a preliminary draft LTTD Treatability Study Report. Kiber will then incorporate responses to Halliburton NUS' comments on the preliminary draft report into a final draft report which will be submitted by Halliburton NUS to U.S. EPA. With Kiber's assistance, Halliburton NUS will respond to U.S. EPA's comments on the final draft report and incorporate these responses into a final LTTD Treatability Study Report.

The preliminary draft, final draft, and final LTTD Treatability Study Reports will include the following information:

- Description of the treatability testing, including the LTTD process and the tests performed,
- Results for all tests performed for the treatability study, documentation of test procedures and variations from established procedures,
- Interpretation of tests results
- Recommendations for optimum on-site treatment reagents
- Uncertainties that may affect effectiveness of recommended reagents in full-scale use
- Conceptual Design for a full-scale LTTD system
- Budget-type cost estimate (\pm 25 percent accuracy) of capital expenditure and operation and maintenance of a full-scale LTTD system
- Discussion of ways, means and/or additional studies that may help further optimize the process in the full-scale LTTD system
- Appendices documenting sample tracking, chain-of-custody, test logs, test data, quality control tests, QC summary of tests, and typical computations and data reduction calculations.

12.0 SCHEDULE

Halliburton NUS and Kiber will make every effort to maintain the schedule shown below.

The LTTD treatability study schedule is as follows:

MILESTONES	DATE
Request For Proposal Issued	12/01/93
Bids Received	12/21/93
Subcontract Award to Kiber	02/18/94
Treatability Samples Received by Kiber	02/22/94
Preliminary Draft Treatability Study Report Issued by Kiber to Halliburton NUS	04/22/94
Final Draft Treatability Study Report Issued by Halliburton NUS to U.S.EPA	05/06/94
Receipt of Comments From U.S.EPA	05/20/94
Final Treatability Study Report Issued by Halliburton NUS to U.S. EPA	06/03/94

13.0

MANAGEMENT AND STAFFING

The Halliburton NUS Project Manager for the Raymark Industries Site EE/CA is **Ms. Heather Ford**. Ms. Ford coordinates all engineering and cost estimating activities and is responsible for the quality of all work performed for this project. **Mr. Jean-Luc Glorieux, P.E.** is the Task Manager for the bench-scale LTDD treatability study.

The Kiber Project Manager for the bench-scale LTDD treatability study is **Mr. Thomas Harper**. Mr. Harper will be responsible for and coordinate all of Kiber's activities for this project and will interface directly with Mr. Glorieux at Halliburton NUS.

Thermal treatment consulting services for the evaluation of the treatability study results and for the preparation of the Conceptual Design and cost estimates for the full-scale LTDD system will be provided to Kiber by **Four Nines Inc.** of Plymouth Meeting, Pennsylvania.

The treatability study analytical work will be performed by Kiber at their test facility with the exception of the analyses for asbestos and PCBs. Asbestos analyses will be performed by **Hygeia Laboratories** of Atlanta, Georgia. PCBs analyses will be performed by **Triangle Laboratories** of Houston, Texas.

14.0 OTHER ADMINISTRATIVE REQUIREMENTS

14.1 Meetings

One (1) meeting will be held at Kiber's testing facility in Atlanta, Georgia during the bench-scale LTTD treatability study. The meeting duration will be one (1) day or less. The meeting will likely take place during the actual testing so that Halliburton NUS may observe Kiber's conformance to this LTTD Treatability Study Work Plan and so that preliminary test results can be presented and discussed. This meeting may also occur as a telephone conference, at the option of Halliburton NUS.

14.2 Compliance and Permits

Kiber will be responsible for complying with Federal, State, and local regulations and for obtaining, maintaining, and paying for any permits and licenses necessary to perform the work for the bench-scale LTTD treatability study.

RCRA

On July 9, 1988, U.S. EPA promulgated regulations which provide an exclusion from RCRA requirements for samples which contain hazardous waste and which are required for treatability testing, subject to certain conditions. 40 CFR Part 261.4(e) excludes treatability samples from regulation as hazardous waste and, accordingly, excludes treatability laboratories from regulation as treatment, storage, and disposal (TSD) facilities. This exclusion also applies during generation, accumulation and storage by the generator, and shipment to the lab provided that:

- Mass does not exceed 1,000 kg of any non-acute hazardous waste, 1 kg of acute hazardous waste (40 CFR Part 261.33(e)) or 250 kg of waste material, water or debris contaminated with acute, hazardous waste for each waste stream and each process being evaluated.
- Mass of each sample shipment does not exceed the above weights.
- Samples are packaged so as not to leak, spill or vaporize.
- Transportation complies with Department of Transportation (DOT), United States Postal Service (USPS), or other applicable shipping requirements.

- Sample is shipped to a laboratory which is either excluded under 40 CFR Part 261.4 or has RCRA permit or interim status.
- Records regarding shipping, contracts, quantities, lab identify, shipment dates and ultimate disposition of waste must be kept and maintained for three (3) years by the generator or collector.
- Daily records regarding sample inventory, management, utilization for treatment or analytical purposes, and disposition of treatment residues or unused sample are maintained by the treatability laboratory.

In certain conditions, U.S. EPA may also grant an exclusion, on a case-by-case basis, for requests covering additional quantities up to 500 kg of non-acute hazardous waste; 1 kg of acute hazardous waste; and 250 kg of soil-waste materials, water or debris contaminated with acute hazardous wastes.

Laboratories performing treatability studies are not subject to RCRA (40 CFR Parts 261, 124, 262-266, 268 and 270, 3010 notification) provided that:

- Written notification is made to the prime environmental agency in the state in which the study is to be conducted by the laboratory that will be conducting treatability studies.
- U.S. EPA identification number is obtained.
- No more than 250 kg daily of "as received" wastes is subject to initiation of treatment in all treatability studies.
- Total of as-received wastes stored does not exceed 1,000 kg. The total can include 500 kg of soil-waste materials, water or debris contaminated with acute hazardous waste or 1 kg of acute hazardous waste; not including treatability study residues, or treatment materials.
- All sample material and related residues must be properly disposed within 90 days after study is completed or 1 year after the sample is shipped to laboratory.
- Treatability study does not involve placement of wastes on land or open burning.

The laboratory must keep various records, and make an annual report to the prime environmental agency in the state in which the study is to be conducted.

Kiber will be responsible for compliance with the requirements specified under 40 CFR Part 261.4 for the treatability exclusion. This outline of the requirements 40 CFR Part 261.4 is provided for informational purposes only, and is not intended to be an all inclusive summary.

TSCA

In addition, Kiber will comply with all applicable Toxic Substances Control Act requirements, and have approved permits, if necessary, to perform the treatability study.

14.3 Confidentiality

Kiber and their lower-tier subcontractors may claim confidentiality on any and all parts of their proposed LTDD process. Pertinent documents may be stamped as such but must still be submitted to Halliburton NUS or U.S. EPA. No such stamped documents will be released to the public by Halliburton NUS or the U.S. EPA. However, the data produced using processes identified as confidential will not be considered to be confidential.

APPENDIX A

KIBER CORPORATE QUALITY ASSURANCE/QUALITY CONTROL PLAN

APPENDIX B

KIBER CORPORATE HEALTH & SAFETY PLAN

APPENDIX B

**REPORT TO HALLIBURTON NUS
ON LOW TEMPERATURE THERMAL DESORPTION TESTING
PREPARED BY KIBER**

(SUBMITTED IN SEPARATE BINDER)

APPENDIX C
COST SENSITIVITY ANALYSIS

COST ESTIMATE – SENSITIVITY ANALYSIS NO. 1
THERMAL TREATMENT
RAYMARK INDUSTRIES, INC. SITE

40 TONS, WET, PER HOUR (TPH) CAPACITY
PURCHASE OF EQUIPMENT, INSTALLATION, AND OPERATION OF TREATMENT PLANT
[AT 30% FEE & PROFIT RATE AND RECOVERABLE SALVAGE VALUE]

VOLUME IN CUBIC YARDS	300000	150000	50000
VOLUME IN TONS	450000	225000	75000
FACTORS (1)			
PROCESS RATE (TPH)	40	40	40
HOURS	11250	5625	1875
DAYS	1406	703	234
ON-LINE RATE	0.7	0.7	0.7
ACTUAL HOURS	16071	8036	2679
ACTUAL DAYS	2009	1004	335
FUEL CONSUMPTION @ MM BTUH	96.85	96.85	96.85
POWER CONSUMPTION (HP)	600	600	600
GENERAL & ADMIN. COSTS @ 10%	0.1	0.1	0.1
CONTINGENCY @ 20%	0.2	0.2	0.2
ENGINEERING @ 10%	0.1	0.1	0.1
FEE & PROFIT @ 30%	0.3	0.3	0.3
DEPRECIATION (2)	100%	100%	61%
1.0 DIRECT COSTS			
CAPITAL (EQUIPMENT, ETC.)	\$3,000,000	\$3,000,000	\$3,000,000
SALVAGE VALUE (2)	\$0	\$0	(\$1,170,000)
SITE PREP./PLACEMENT	\$500,000	\$500,000	\$500,000
FUEL @\$6/MM BTU	\$9,339,107	\$4,669,554	\$1,556,518
ELEC./POWER @ \$0.12/KWH	\$863,229	\$431,614	\$143,871
MAINTENANCE	\$386,986	\$193,493	\$64,498
TAXES & INSURANCE	\$472,123	\$236,062	\$78,687
SOIL LOADER	\$562,480	\$281,240	\$93,747
ASH CARTS	\$242,991	\$121,496	\$40,499
SAMPLING	\$2,249,920	\$1,124,960	\$374,987
LABOR @ \$30/HR, 7 PEOPLE	\$3,375,000	\$1,687,500	\$562,500
M&IE @ \$65/DAY	\$914,063	\$457,031	\$152,344
SUBTOTAL DIRECT COSTS	\$21,905,899	\$12,702,950	\$5,397,650
GENERAL & ADMIN. COSTS	\$2,190,590	\$1,270,295	\$539,765
CONTINGENCY @ 20%	\$4,381,180	\$2,540,590	\$1,079,530
FUEL CONTINGENCY @ 10%	\$933,911	\$466,955	\$155,652
ENGINEERING @ 10%	\$2,190,590	\$1,270,295	\$539,765
SUBTOTAL COSTS	\$31,602,169	\$18,251,085	\$7,712,362
FEE & PROFIT @ 30%	\$9,480,651	\$5,475,325	\$2,313,708
TOTAL DIRECT COSTS	\$41,082,820	\$23,726,410	\$10,026,070
2.0 FIXED COSTS			
TRIAL BURN TESTING	\$150,000	\$150,000	\$150,000
CONTRACTOR START-UP/SHUTDOWN	\$46,286	\$46,286	\$46,286
PERMITS/CONSULTANTS	\$125,000	\$125,000	\$125,000
MOB./DEMOB.	\$500,000	\$500,000	\$500,000
START-UP/SHUTDOWN, 3 @ 45 DAYS	\$46,300	\$46,300	\$46,300
M&IE @ \$65/DAY	\$6,750	\$6,750	\$6,750
SUBTOTAL FIXED COSTS	\$874,336	\$874,336	\$874,336
GENERAL & ADMIN. COSTS	\$87,434	\$87,434	\$87,434
CONTINGENCY @ 20%	\$174,867	\$174,867	\$174,867
SUBTOTAL COSTS	\$1,136,637	\$1,136,637	\$1,136,637
FEE & PROFIT @ 30%	\$340,991	\$340,991	\$340,991
TOTAL FIXED COSTS	\$2,614,265	\$2,614,265	\$2,614,265
TOTAL COSTS	\$43,697,085	\$26,340,675	\$12,640,335
3.0 UNIT COSTS			
TREATMENT COST (\$/CY)	\$145.66	\$175.60	\$252.81
TREATMENT COST (\$/TON)	\$97.10	\$117.07	\$168.54

NOTES:

- (1) COSTS FOR TREATMENT ONLY (CHUTE-TO-CHUTE). MATERIALS EXCAVATION, HANDLING AND DISPOSAL OF TREATED MATERIALS, ETC. ARE NOT INCLUDED. CONTINGENCY AND FEE & PROFIT FACTORS FROM FOUR NINES, INC. ESTIMATE. G & A AND ENGINEERING COST FACTORS SELECTED BY HNUS.
- (2) STRAIGHT-LINE DEPRECIATION BASED ON 1.5 YEAR AMORTIZATION PERIOD.

COST ESTIMATE – SENSITIVITY ANALYSIS NO. 2
THERMAL TREATMENT
RAYMARK INDUSTRIES, INC. SITE

40 TONS, WET, PER HOUR (TPH) CAPACITY
PURCHASE OF EQUIPMENT, INSTALLATION, AND OPERATION OF TREATMENT PLANT
[15% FEE & PROFIT, NO SALVAGE VALUE]

VOLUME IN CUBIC YARDS	300000	150000	50000
VOLUME IN TONS	450000	225000	75000
FACTORS (1)			
PROCESS RATE (TPH)	40	40	40
HOURS	11250	5625	1875
DAYS	1406	703	234
ON-LINE RATE	0.7	0.7	0.7
ACTUAL HOURS	16071	8036	2679
ACTUAL DAYS	2009	1004	335
FUEL CONSUMPTION @ MM BTUH	96.85	96.85	96.85
POWER CONSUMPTION (HP)	600	600	600
GENERAL & ADMIN. COSTS @ 10%	0.1	0.1	0.1
CONTINGENCY @ 20%	0.2	0.2	0.2
ENGINEERING @ 10%	0.1	0.1	0.1
FEE & PROFIT @ 15%	0.15	0.15	0.15
DEPRECIATION (2)	100%	100%	100%
1.0 DIRECT COSTS			
CAPITAL (EQUIPMENT, ETC.)	\$3,000,000	\$3,000,000	\$3,000,000
SALVAGE VALUE (2)	\$0	\$0	\$0
SITE PREP./PLACEMENT	\$500,000	\$500,000	\$500,000
FUEL @\$6/MM BTU	\$9,339,107	\$4,669,554	\$1,556,518
ELEC./POWER @ \$0.12/KWH	\$863,229	\$431,614	\$143,871
MAINTENANCE	\$386,986	\$193,493	\$64,498
TAXES & INSURANCE	\$472,123	\$236,062	\$78,687
SOIL LOADER	\$562,480	\$281,240	\$93,747
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SAMPLING	\$2,249,920	\$1,124,960	\$374,987
LABOR @ \$30/HR, 7 PEOPLE	\$3,375,000	\$1,687,500	\$562,500
M&IE @ \$65/DAY	\$914,063	\$457,031	\$152,344
SUBTOTAL DIRECT COSTS	\$21,905,899	\$12,702,950	\$6,567,650
GENERAL & ADMIN. COSTS	\$2,190,590	\$1,270,295	\$656,765
CONTINGENCY @ 20%	\$4,381,180	\$2,540,590	\$1,313,530
FUEL CONTINGENCY @ 10%	\$933,911	\$466,955	\$155,652
ENGINEERING @ 10%	\$2,190,590	\$1,270,295	\$656,765
SUBTOTAL COSTS	\$31,602,169	\$18,251,085	\$9,350,362
FEE & PROFIT @ 15%	\$4,740,325	\$2,737,663	\$1,402,554
TOTAL DIRECT COSTS	\$36,342,495	\$20,988,747	\$10,752,916
2.0 FIXED COSTS			
TRIAL BURN TESTING	\$150,000	\$150,000	\$150,000
CONTRACTOR START-UP/SHUTDOWN	\$46,286	\$46,286	\$46,286
PERMITS/CONSULTANTS	\$125,000	\$125,000	\$125,000
MOB./DEMOB.	\$500,000	\$500,000	\$500,000
START-UP/SHUTDOWN, 3 @ 45 DAYS	\$46,300	\$46,300	\$46,300
M&IE @ \$65/DAY	\$6,750	\$6,750	\$6,750
SUBTOTAL FIXED COSTS	\$874,336	\$874,336	\$874,336
GENERAL & ADMIN. COSTS	\$87,434	\$87,434	\$87,434
CONTINGENCY @ 20%	\$174,867	\$174,867	\$174,867
SUBTOTAL COSTS	\$1,136,637	\$1,136,637	\$1,136,637
FEE & PROFIT @ 15%	\$170,496	\$170,496	\$170,496
TOTAL FIXED COSTS	\$2,443,769	\$2,443,769	\$2,443,769
TOTAL COSTS	\$38,786,264	\$23,432,517	\$13,196,685
3.0 UNIT COSTS			
TREATMENT COST (\$/CY)	\$129.29	\$156.22	\$263.93
TREATMENT COST (\$/TON)	\$86.19	\$104.14	\$175.96

NOTES:

- (1) COSTS FOR TREATMENT ONLY (CHUTE-TO-CHUTE). MATERIALS EXCAVATION, HANDLING AND DISPOSAL OF TREATED MATERIALS, ETC. ARE NOT INCLUDED. CONTINGENCY FACTOR FROM FOUR NINES, INC. ESTIMATE.
- CONTINGENCY, G & A, AND ENGINEERING COST FACTORS SELECTED BY HNUS.
- (2) STRAIGHT-LINE DEPRECIATION BASED ON 1.5 YEAR AMORTIZATION PERIOD.